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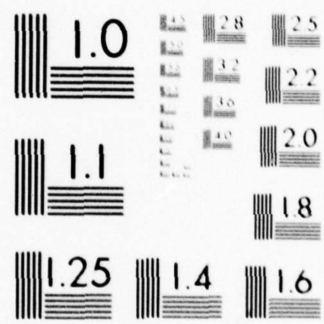

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OPERATIONAL PILOT FACTORS ANALYSIS REPORT

B. A. OLSON

Honeywell Systems and Research Center
2700 Ridgway Parkway
Minneapolis, Minnesota 54413

JULY 1979

AEROSPACE MEDICAL RESEARCH LABORATORY
AEROSPACE MEDICAL DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

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TECHNICAL REVIEW AND APPROVAL

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This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

Charles Bates

CHARLES BATES, JR.
Chief
Human Engineering Division
Aerospace Medical Research Laboratory

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes the studies and analysis work done to identify performance requirements with respect to the operator who will wear the helmet and use the helmet sight/display system in the operational situation. Its purpose is to identify and document performance requirements for the IHMS/D equipment with respect to: Pilot population anthropometric and visual characteristics. Environmental effects of ambient light, field of view, acceleration, vibration, noice and space available. Display information requirements of accuracy, format, brightness, contrast, and the control respone of the system. (See reverse)

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SECTION I
INTRODUCTION

This report presents design considerations for the Integrated Helmet Mounted Sight/Display (IHMS/D) system with respect to the operator who will wear the helmet and use the sight/display system in the operational situation. This report identifies and documents performance requirements for the IHMS/D equipment with respect to:

- Pilot population anthropometrics and visual characteristics
- Environmental effects of ambient light, field of view, acceleration, vibration, noise, and space available
- Display information requirements of accuracy, format, brightness, contrast, and control response of the system

In May 1972, Honeywell undertook the Integrated Helmet Mounted Sight/Display (IHMS/D) development program for the Air Force to provide the required technical services, materials, and facilities necessary to perform the development, engineering design, fabrication, assembly, integration, and testing of the IHMS/D design. The approach of this development program was to integrate Honeywell's capability in the design, development, and production of helmet mounted sights (Figures 1 and 2) with advances in HMS/D technology, specifically the development of a visor-projected helmet mounted display (HMD) as shown in Figure 3. The major areas of the development work included

- Visor fabrication techniques to meet the optical requirements of video displays while providing for low-cost quantity production

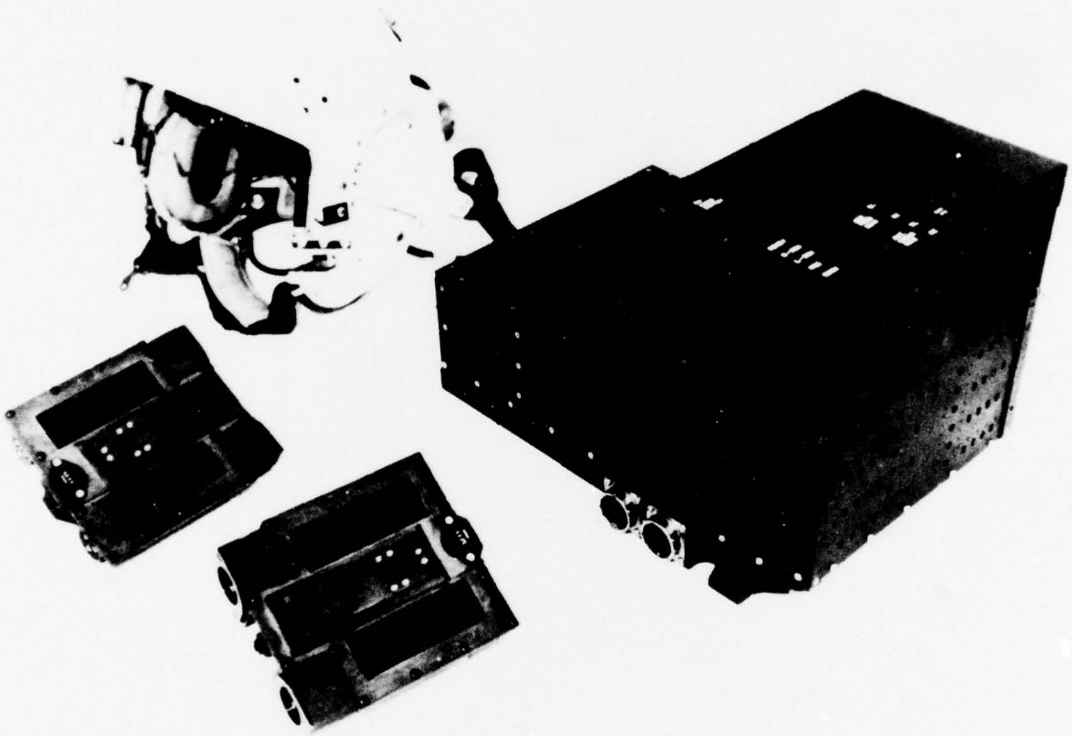


Figure 1. Helmet Mounted Sight System

Figure 2. Visor Reticle Helmet

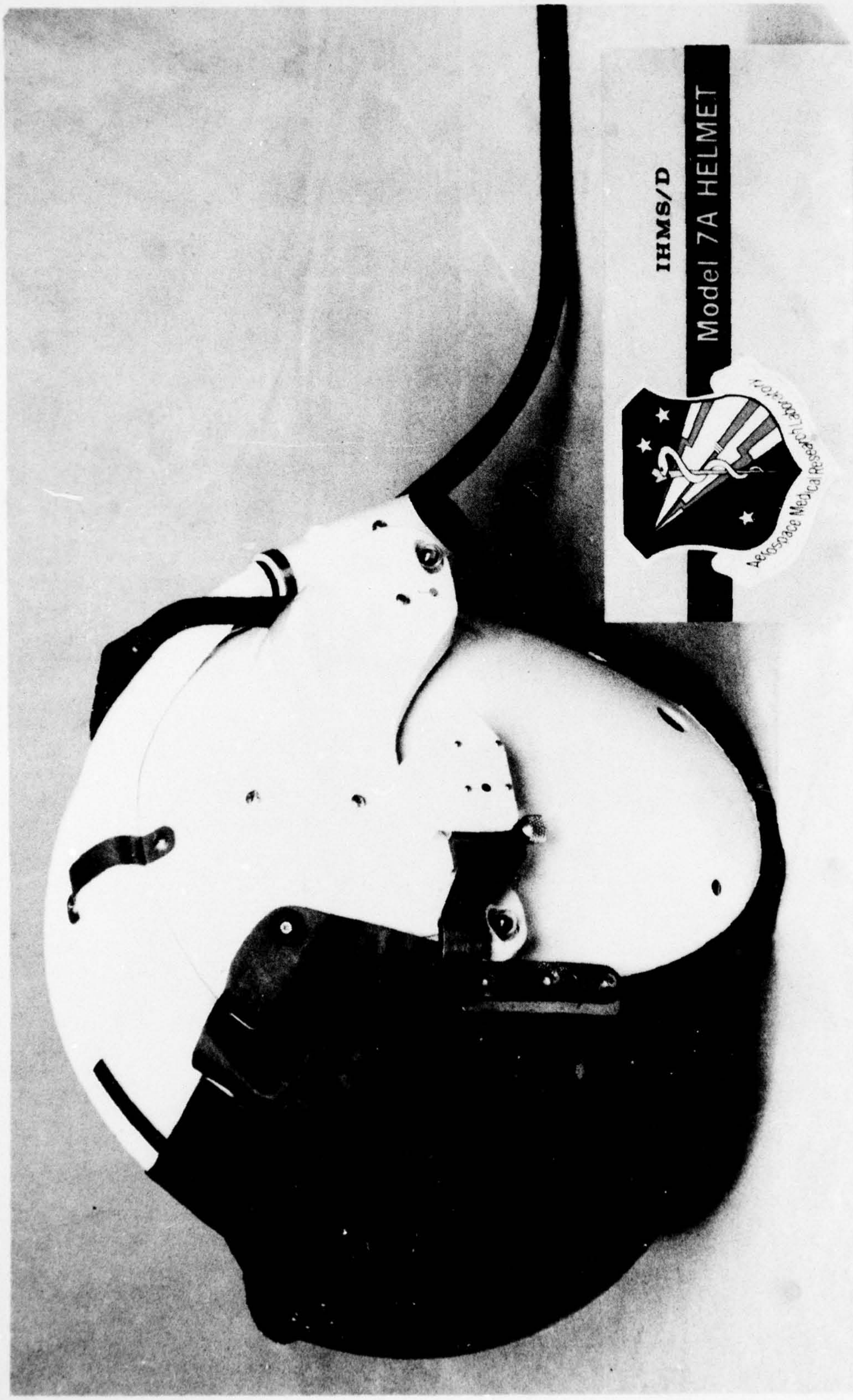


Figure 3. Visor-Projected Helmet Mounted Display

- Visor coating and testing techniques needed to optimize the human and optical performance of the IHMS/D

- Optical design concepts for extending the displayed field of view while maintaining or improving optical system performance. This effort included consideration of optical techniques for image transfer from the cathode-ray-tube (CRT) face to the projection system by means of fiber optics, relay lens system, single fiber devices, or other appropriate concept.

- Consideration of pilot (wearer) human factors on the overall design including anthropomorphic variability, need and range of adjustments, weight and balance effects, differential adaptation, eye dominance, helmet envelope, and peripheral vision

- Optical design concepts for incorporating a helmet-mounted camera head into the overall IHMS/D design; the camera axis to be coaxial with the video display

- Electronic computation and helmet installation requirements for incorporation of roll sensing and display stabilization (about the roll axis)

The overall objective of this program was to design, develop, and fabricate an IHMS/D that could be used efficiently and effectively in USAF visually coupled systems and whose end result would be a production release. This system will permit the use of pilot/crew capability for aiming and tracking while simultaneously viewing information developed from airborne systems or remote sensors. The design approach to achieve the objective was (1) early operational testing of prototype systems for engineering data, (2) a production design based on a comprehensive review of operational problems and crew factors, and (3) an engineering program, engineering model build, and

prototype program which will provide the engineering data and design information required for production release. The program was directed toward producing a flightworthy system acceptable to operational personnel.

Honeywell has conducted development work on helmet mounted displays (HMD) since 1963. Nicholson demonstrated the feasibility of head mounted devices in 1963 (Reference 1). These data were used in the development of the helmet mounted sight (HMS) system. The sight enables a pilot to perform tasks, normally requiring two men, through a "heads-up", "hands-free" weapon control and "heads-up" display of a sight reticle of target information such as sensor lock on and target confirmation.

Modern airborne tactics have proved that tactical and air superiority aircraft equipped with improved target acquisition and fire control systems possess an added superiority over hostile aircraft. Actual flight tests of the HMS system have demonstrated significant improvement in aircraft performance by giving the pilot an easy-to-operate, fast-reaction, off-boresight target acquisition system for fire control sensors and weapons.

Since visual acquisition of the target is vitally important in the air-to-air combat environment, the line-of-sight (LOS) parameters are an important source of information to direct various sensors on the aircraft towards the target. These sensors have additional information that is valuable to the pilot. For example, radar, IR, and LLLTV can provide navigation and identification information when presented to the pilot's eye. The helmet display extends the capability of the helmet sight. The helmet display provides a direct visual feedback to the operator of where the sensor(s) are pointing.

The HMD completes the visual control system to give a visually coupled system. The helmet display includes

- Display generator, a monocular CRT
- Projection optics to collimate the image
- Part reflecting visor
- Sun visor for ambient light control

The image on the HMD is

- Seen at optical infinity
- Similar to a large screen television picture
- Seen as an overlay on the real world
- Seen regardless of head position

The image on the HMD is always available at the operator's command.

The primary purpose of the helmet is to provide protection to the pilot's head from impacts. Pilots wear helmets for

- Protection -- visual, thermal, acoustic, impact and ballistic
- A base for mounting required equipment; e.g., oxygen, communication, visor, and VCS

The study reported herein considered the requirements to be placed on VCS equipment to prevent it from interfering with or degrading the performance of the helmet in its other capacities.

SECTION II
SUMMARY

The study "Aircrew Protective Headgear Study Program" (Reference 2) defined a helmet problem. The study concluded that 30 percent of the USAF helmet wearing population are unhappy with their present helmet for one or more reasons. The addition of the HMD to the helmet may contribute to the general problem since it

- Adds weight to the standard helmet
- Wires the pilot's head to high voltage
- May add eccentric loads to the helmet
- Adds an image into the pilot's normal field of view

As part of its IHMS/D development program, Honeywell studied the pilot-related requirements to be placed on the HMD. These included the items listed above in addition to several anthropometric relations between the pilot and the HMD. These latter included

- An eye reference point for location of the system optics on the helmet was required and was defined by review of available USAF AMRL anthropometric data.

- The angle at which pilots wear their helmets was needed by the helmet designers in order to define the display direction relative to the zero position of the helmet sight system. In a sample of 54 fighter pilots, the average angle (LOS-shell angle) was 13.6 degrees. The angle range was from 0 to 20 degrees. The average dimension from the brim to the eye was 1.94 inches. The dimension range was 1.61 to 2.56 inches (Reference 3).

- Motion of the helmet relative to the head during g loads is of interest in defining HMD system parameters. The helmet moves due to compression of skin and helmet padding, due to eccentric loading of the helmet, and due to movement of the skin with respect to the skull plus some minimum movement of the helmet pad on the hair and skin. Related problems are the total weight and the balance of the helmet assembly.

The objective of the study reported herein is to identify IHMS/D performance requirements with respect to the pilot. The IHMS/D must be designed such that it does not cause accidents, personal injury, or damage to equipment and does not degrade the protection functions offered by the standard helmet, HGU-2A/P. The IHMS/D must be designed to enhance the performance of the weapon system.

The results of this study demonstrate that the IHMS/D can be worn by the operator to increase his ability to locate and track visible targets as well as those seen only by a remote sensor. The IHMS/D design does not degrade the protection offered by the standard HGU-2A/P for the mechanical and electrical hazards considered in this study. Two additional mechanical hazards for aircrew with respect to the helmet are ejections and crash landings. The protection of the IHMS/D for these major hazards must be demonstrated in tests that are beyond the scope of this study.

SECTION III
DISCUSSION

ANTHROPOMETRY

Anthropometry is that part of anthropology that measures the human body to determine differences within a given population or between populations. These data are useful to the designer to describe the user's sizes and the variability of these sizes. Human dimensions are measured in a standardized manner; standardization is critical if data from one population are to be compared with data from a different population. Detail descriptions of measurement procedures are presented in Reference 4.

Knowledge of the weight, volume, and center of mass of human body segments is significant to research and design in diverse fields. These data for the head/neck assembly are significant for the IHMS/D design. Unfortunately, these data, derived from a small number of cadavers, must be extrapolated to the dynamic living body (Reference 5).

Personnel in all flight categories are well defined by 190 body measurements. Most of these measurements are considered conventional by physical anthropologists. However, some new eye location measurements had to be generated to develop the IHMS/D, and to ensure that this equipment would fit the using population.

A fundamental problem for the IHMS/D design was to establish an eye reference point for locating the system optics on the helmet. The most extensive definition of Air Force personnel, in all flight categories, was documented in WADC TR 52-321, "Anthropometry of Flying Personnel -- 1950." More than 4000 personnel were measured. These data were updated by a new study,

"1967 USAF Anthropometric Survey Descriptive Data." Figure 4, which defines the HMD optics adjustment requirement envelope, is based on these two reports.

Eye Location in Head

Although 190 human body dimensions are documented in Reference 6, the center and leading edge of the eye has not been dimensioned from the forehead and top of the head. These are required dimensions in the IHMS/D design. A method was developed to determine the reference eye location from the existing anthropometric data. The method was coordinated with and concurred in by the Anthropometry Laboratory, AMRL.

Several questions about eye location and head dimensions versus the 1967 USAF Anthropometric Survey Data were considered.

1. The extreme values of the wall to nasal root length exceed the head length, variable 150 versus variable 182. Is this an error?

   The apparent discrepancy of these data appears in all the anthropometry reports. The error is probably due to a difference in techniques. Two different instruments are used to measure the two dimensions. The mean values for these dimensions have the correct relationship.

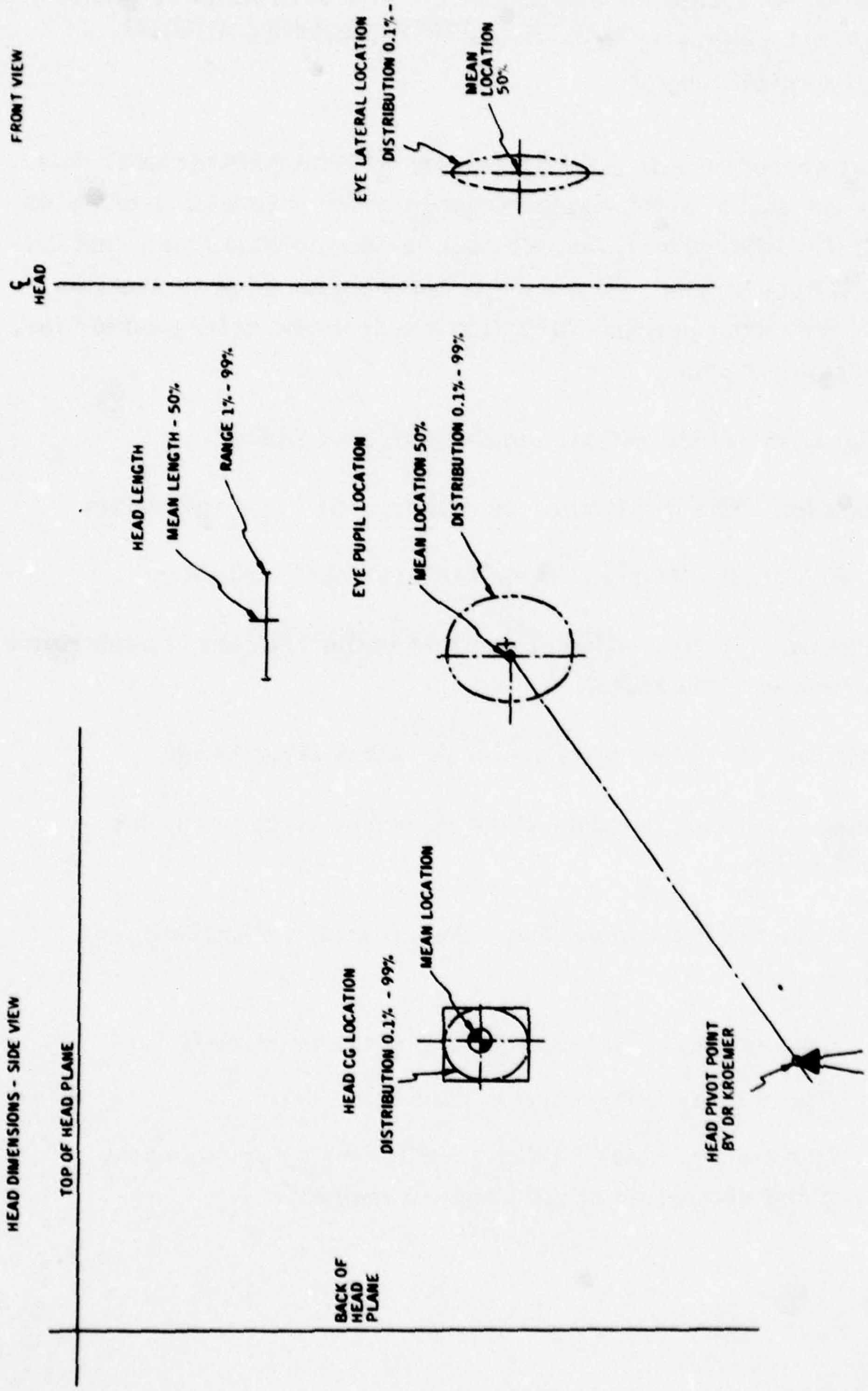


Figure 4. Recommended Design Reference

2. How do we locate the eye in space? Is it acceptable to use, external canthus + $\frac{(\text{nasal root length - external canthus})}{2}$ = wall to pupil length?

   That approach is in good agreement with the photographic data. Use as wall to pupil length: external canthus to wall length plus 1/2 the difference of the external canthus to wall length and the nasal root length. To get the 3rd dimension of pupil location use 1/2 of the interpupilary distance from the head's centerline, midsagittal plane.

3. What is the effect of hair length on helmet fitting?

   Unknown. The USAF pilot wear their hair relatively short.

4. At what angles (in pitch) do pilots wear their helmets?

   Unknown. Their feeling of comfort is the primary consideration for helmet pitch angle.

5. What are the characteristics of the extra large head?

   There is nothing peculiar about the extra large head, just scaled higher.

6. What are the disadvantages of thicker than normal helmet padding?

   a. Oxygen mask hardware mounting for mask seal.

   b. Visor fit over the oxygen mask for ejection.

   c. Ear cup seal may be destroyed, thereby reducing the noise protection of the helmet assembly.

7. What is the minimum thickness pads on top and forehead?

   Nominal pad thicknesses are: thin = 0.25 inch
   medium = 0.5 inch
   thick = 0.75 inch

   A report on helmets as a protective device has been published (Reference 2.)

The need exists to specify the length dimension from the forehead to the eye leading edge for the IHMS/D design. On the basis of the "1967 USAF Anthropometric Survey Descriptive Data," the forehead to eye length was developed as shown in Figure 5. The difference between lengths, nasal root, and external canthus is constant across percentiles of the USAF population within 0.10 inch. The range of the difference by percentile for 1 percent to 99 percent is 0.31 inch to 0.45 inch. The mean difference is 0.35 inch. The median difference is 0.36 inch. The standard deviations of mean lengths are 0.25 inch for head length, 0.32 inch for external canthus, and 0.34 inch for nasal root. The forehead to eye length was measured on five Honeywell engineers who were representative of the USAF pilot population size. From this sample, the length dimension range was 0.375 to 0.625. Therefore, it is recommended that the eye length dimension, described by Figure 5, be used to design the IHMS/D.

Helmet Brim Location

The helmet brim must be fixed with respect to the user's eye for the IHMS/D design. The Honeywell sample of 54 fighter pilots indicated that pilots wear their helmets at various angles (Reference 3). From these data, the average angle (line of sight to shell brim) was 13.6 degrees. The angle range was from zero to 20 degrees. The average dimension from the brim to the eye was 1.94 inches. The dimension range was from 1.61 inches to 2.56 inches.

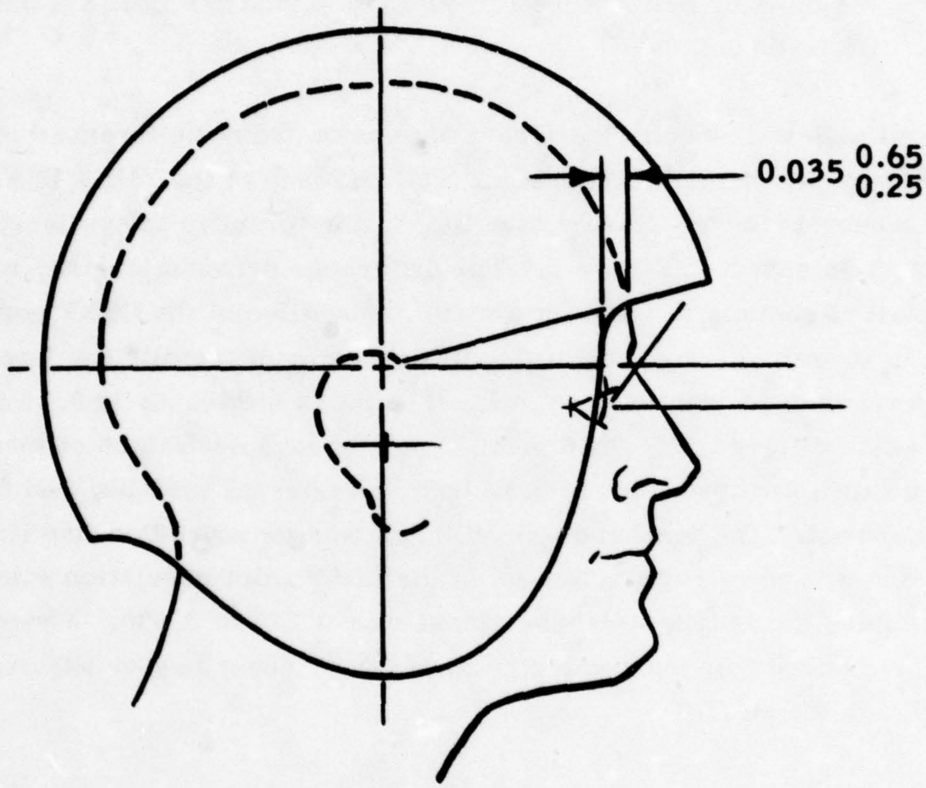


Figure 5. Forehead to Eye Length

The design eye position with respect to the helmet is assumed to be as shown in Figures 6 and 7. This eye position will be fixed, at the time of fitting the helmet to the pilot's head, by the shape of the custom fit liner.

The angle of the helmet brim and the vertical distance between the brim and the pupil are based on the average measured position from a sample of 54 pilots. The helmet-mounted equipment will be designed to provide for an unobstructed 54-degree vertical field of view.

Adjustment Definition

The pilot is only implicitly identified in the Anthropometric data. In the 1950 survey, 46 percent of the sampled population were pilots--28.4 percent multi-engine pilots, 5.2 percent fighter pilots, 12.2 percent student pilots. The mean value of the various dimensions are given by aerorating subgroup. The 1967 survey did not identify dimension mean values by aerorating subgroups.

In the 1950 survey, (Reference 4) the comparison of pilot dimensions mean value with the total sample mean value indicates that the data describe the pilot population. For example:

1. Weight (pounds)

• Sample population mean	163.66
• Pilot-multi engine mean	165.7
• Pilot-fighter mean	159.0
• Pilot-student mean	159.1

2. Stature (inches)

• Sample population mean	69.11
• Pilot-multi engine mean	69.44
• Pilot-fighter mean	68.81
• Pilot-student mean	69.16

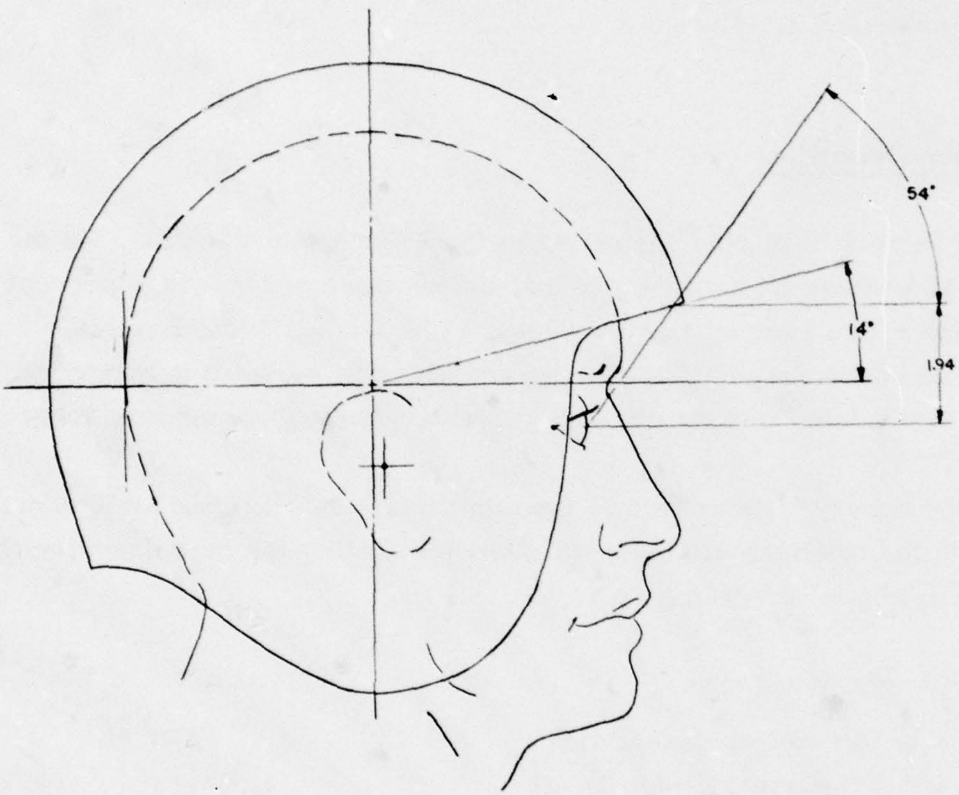


Figure 6. Large Helmet (for 50th Percentile Head)

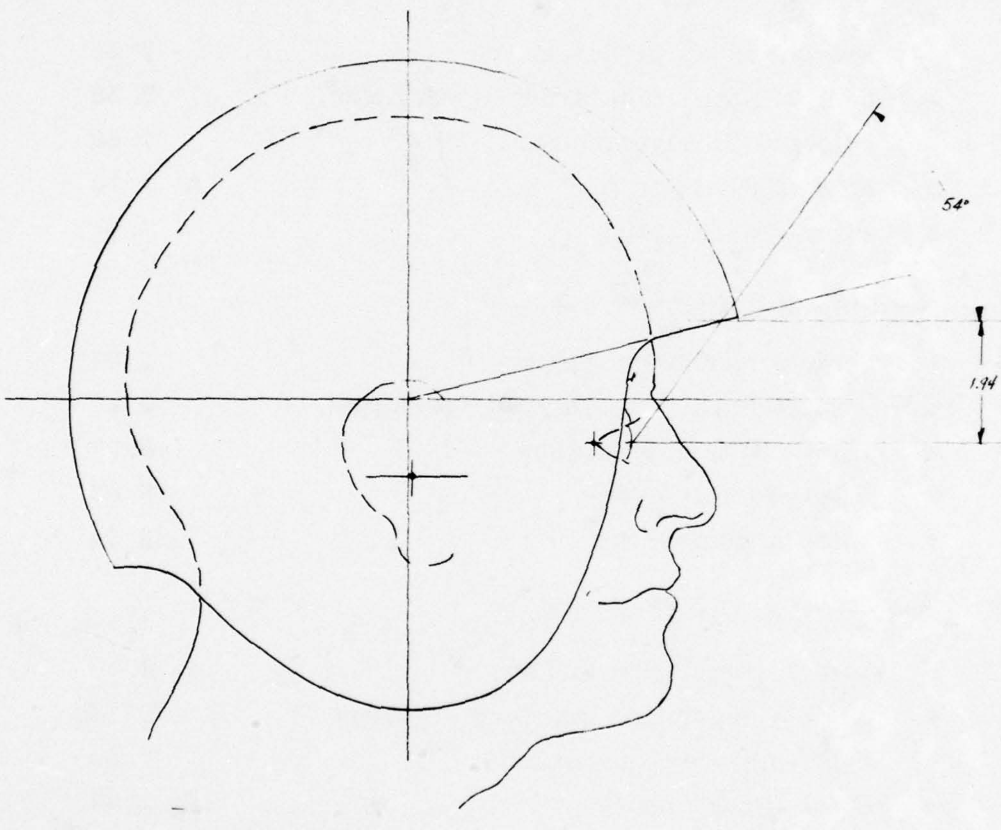


Figure 7. Extra Large Helmet (for 95th Percentile Head)

3. Eye height, sitting (inches)

- Sample population mean 31.47
- Pilot-multi engine mean 31.65
- Pilot-fighter mean 31.35
- Pilot-student mean 31.47

4. Head length (inches)

- Sample population mean 7.76
- Sample population standard deviation 0.25
- Pilot-multi engine-mean 7.80
- Pilot-fighter mean 7.74
- Pilot-student mean 7.74

5. Head breadth (inches)

- Sample population mean 6.07
- Sample population standard deviation 0.20
- Pilot-multi engine mean 6.07
- Pilot-fighter mean 6.08
- Pilot-student mean 6.04

6. Interpulilary Distance (inches)

- Sample population mean 2.49
- Sample population standard deviation 0.14
- Pilot-multi engine mean 2.50
- Pilot-fighter mean 2.47
- Pilot-student mean 2.48

The anthropometric survey data (Figure 4) describe the pilot population for the IHMS/D design. Therefore, the design will fit the 1 percent to 99 percent population range as shown.

The pilot's image adjustment capability will be within a 0.25-inch square centered on the normal fitted eye location, eye exit pupil, of the individual. This capability will be provided for both custom-fitted helmets and standard helmets.

Current helmets have some deficiencies. Improper fitting and excessively resilient padding produce a marked decrement in retention, comfort, sound attenuation, and visibility in the upper vertical plane. The pilot will from time to time in a mission make adjustments to his helmet for improved comfort and/or to compensate for padding set. This will change the position of the projected image in the exit pupil of the eye. Therefore, vernier adjustment capability of the projected image will be required.

Major adjustment capability will be available to the personal equipment technician, but will not be required by the wearer of the HMD. The IHMS/D will be adjusted to fit the individual by the personal equipment technician; once these adjustments are made and locked, only vernier adjustment will be required by the pilot.

OPERATIONAL ENVIRONMENT

This study was designed to analyze the effects of operational ambient light, field of view, acceleration, vibration, space available, and installation environment on the IHMS/D. An objective was to develop a design which compensates for these effects wherever possible.

The specific effort in this study was to identify the operational constraints for an IHMS/D. A basic mission profile was taken from the study "Helmet Mounted Sight/Display Applications." The mission profile basic air superiority is described in Figure 8. The air-to-air combat applications are:

- Long-range radar acquisition and optical target identification
- Missile firing involving both passive electro-optical homing missiles and semi-active radar homing missiles
- Fixed gun firing

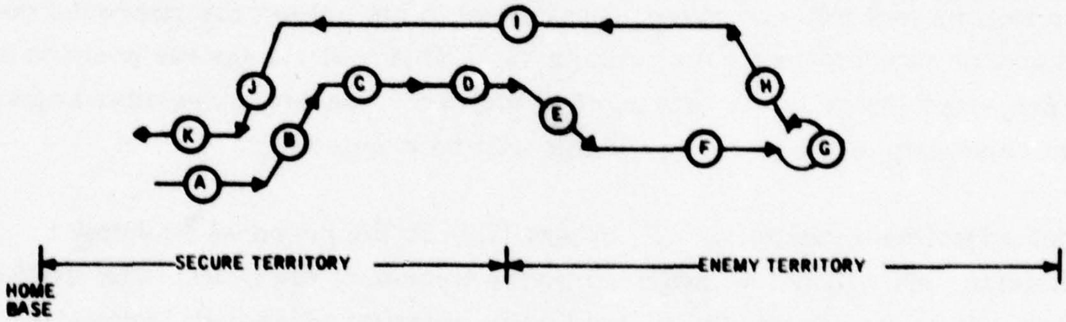


Figure 8. Air Superiority Mission

The following mission profile provides a reasonable balance of conditions over which the IHMS/D must operate; it describes a general operational environment.

MISSION: BASIC AIR SUPERIORITY

PHASES:

A. Warm up and takeoff. Checkout IHMS/D and turn off.

B. Climb - perform minimum fuel climb to formation altitude.

C. Rendezvous - Rendezvous with formation.

D. Cruise - Cruise at optimum speed and altitude for range (approximately 200 nm).

E. Descent - Descend to medium altitude (10,000 feet). Turn on IHMS/D.

F. Cruise - Cruise at 10,000 feet, mach 0.85.

G. Air-to-air combat - Maneuver for three minutes at maximum power at 10,000 feet against enemy fighters.

H. Climb - Perform minimum time climb to cruise altitude.

I. Cruise - Cruise at optimum speed and altitude for range to home base. Turn off IHMS/D.

J. Descent - Descend and fly holding pattern prior to landing.

K. Land - Retain fuel for 20 minutes at maximum endurance at sea level.

Ambient Light

The ambient light in the cockpit when the helmet sight display system is used becomes an important factor. Display contrast must be sufficient so that the smaller details can be seen against an ambient light on the highest scale and yet be visible for nighttime illumination. The variation is quite wide for this application.

The canopy transmission factor is not too important but can be considered as 87 percent for typical enclosures. The average brightness of the upper surface of clouds at noon is 9000 millilamberts, which with the 87 percent factor causes 7830 millilamberts in the cockpit. The HMD should be designed for this background brightness since only darker background will provide better contrast.

Typical ambient illumination values are

- Direct sunlight, midday = 10,000 foot-lamberts
- Clear sky average luminance = 2,000 foot-lamberts
- Cloud cover midday average value = 6,000 foot-lamberts

Figure 9 describes the effects of ambient light transmitted through the projected image versus the image brightness as measured at the CRT. Design factors related to ambient light are

1) Night vision
   - Required or not required
   - Red light, white light, CRT displays light
2) Day vision
   - High ambient light
     - Light transmission
       1. Windshields
       2. Canopies
       3. Visors
     - Haze values
       1. Windshields
       2. Canopies
       3. Visors
   - Luminance
     - Subjective magnitude
     - Stimulus magnitude
     - Electroluminescent display luminance

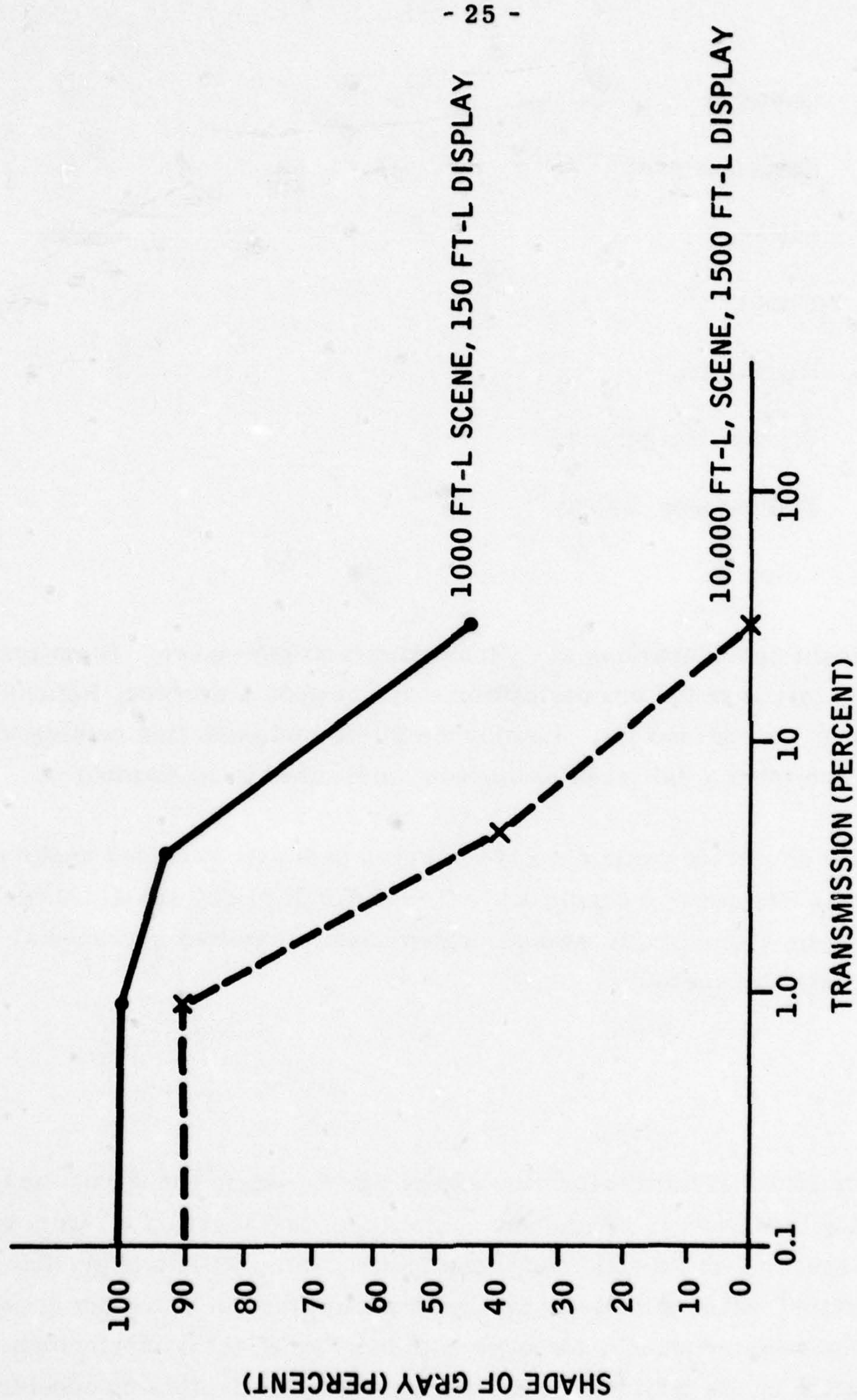


Figure 9. HMD Shades of Gray Resolution

- Contrast
- Shades of gray
- Filters
- Flicker
- Resolution
- Screen (image) size
- Multisensor display
- Color

Two significant considerations are illuminance and luminance. Illuminance is measured in terms of the density of flux incident upon a surface, lumens per square foot or the foot candle. Luminance is the luminous flux coming to the operator's eye from a unit area of surface, measured in footlamberts.

The majority of electro-optic display research data was gathered under static, 1 g, moderate illuminance conditions. It is difficult to extrapolate these data to the real-time dynamic operational environment. Limited operational acceptable data are available.

Vibration

A wide variation in aircraft vibration exists that is dependent on location. The direction of vibration, frequency, amplitude, and location all vary with flight condition and turbulence. Of these factors, amplitude and direction are most important. Studies have shown that the amplitude of vibration is more important than the frequency, although both have an effect on performance. The attenuation of the pilot and seat structure are also factors to consider.

Many of the studies on vibration used a sinusoidal vibration input, although in an operational situation the vibration is more random. Effects that are detrimental at certain frequencies and amplitudes are only occasionally excited, such as during buffeting. Most of this vibration is not detrimental to normal pilot duties, although it may be annoying. Most annoyance occurs below 20 Hz, and vibrations between 3 and 6 Hz are most likely to effect a response since they are at the natural frequency of the pilot. At low frequencies, the pilot's head will vibrate somewhere near the amplitude of the seat, but reaches a peak in the 3- to 6-Hz range. At frequencies above this point, the pilot attenuates the amplitude until, near 70 Hz, the amplitude is down to 10 percent.

It is recommended that the allowable vibration should be 0.08 g as established by WADC for long-time tolerance levels in military aircraft. This can be converted to amplitude by the equation

$$g = KA_{\omega}^{2}$$

where

K = 0.0511

A = amplitude (inches)

ω = frequency (Hz)

For the equipment on the black box level, it is recommended that the usual MIL specifications be used (MIL-STD-810B). These units will be mounted on the aircraft structure and should be tested to standards specified for electronic equipment.

Acceleration

The present acceleration limits specified in the MIL specification should be used for the electronic and optical equipment. These same limits can be applied to the helmet, optical fittings, and accessories. The operational characteristics specified should be incorporated in the acceptance procedures document.

Installation Environment

A simple installation procedure can be developed for various helmet sight applications. Since the observer or pilot now becomes part of the sighting system, the procedure can be tailored to the individual. The procedure may require bench marks, on the canopy or support structure, that can be used as a reference while the pilot calibrates the system to his own liking. With an arrangement of this type, the variations of seat height, pilot build, cockpit variation, or sight display can be compensated by a simple on-sight calibration.

Another advantage of a calibration with the pilot is that many misalignments can be eliminated. Variations in the pilot's physique, position relative to the aircraft, or aircraft irregularities can be compensated by the technique.

Field of View

Existing displays are seldom more than 10 inches across. When viewed at distances of 20 to 30 inches they give an angular field of 19 to 28 degrees. The helmet displays have been built to cover this field of view normally available on panel instruments. The size of the display is usually restricted to a smaller area and need not have a one to one relationship with the real

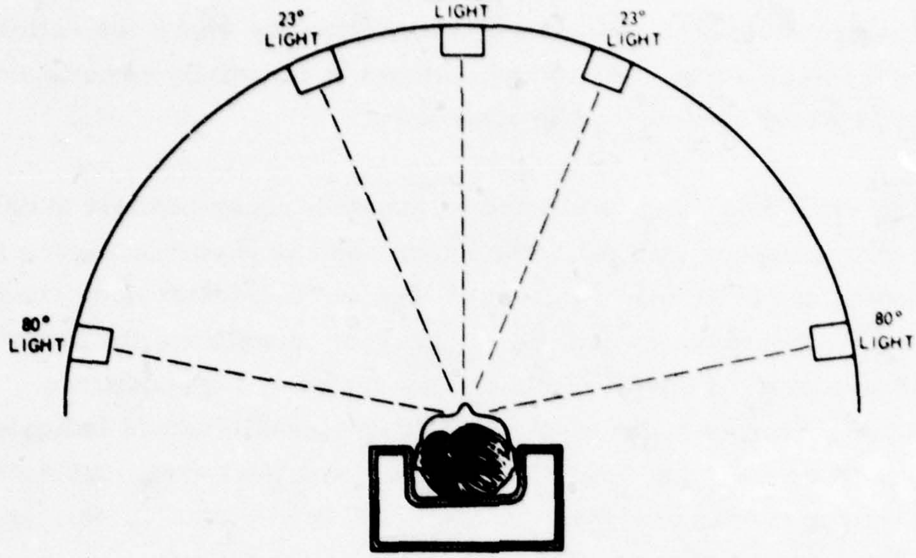
world. One exception to this is a gun sight display where the reticle must move in the real world. For other displays it is usually advantageous to restrict the field of view to a smaller area.

A field of view study was conducted on subjects under positive accelerations and viewing a source of light. The experiment is shown in Figure 10. The results obtained show that the field of view is restricted under conditions of positive acceleration. During these "grayout" conditions the subjects were reduced to a total 46-degree field of view under 4.5-g conditions. At 5.3 g the field of view was reduced to zero. These results would indicate that it is advisable to restrict the field of view to the smallest area consistent with that necessary for proper viewing.

Space Available

The space-available requirements refer to the space on the helmet and supporting electronics, including the cable connections, cable envelope, head rest, and clearance in the cockpit.

The fiber optics bundle has been assigned to the crown of the helmet with the cathode ray at the nape of the helmet. The clearance over the top of the helmet can be adjusted to a certain extent by seat adjustment, although the eye level must also be considered. The fiber optics will probably stay within a 0.75-inch envelope as measured from the top of the helmet. This requirement is not too stringent since the visor track assembly protrudes above the helmet, and the fiber optics bundle is near these envelope limits. The location and size of the cathode ray assembly is more critical. During normal operation this assembly may interfere with the head rest or the head rest support. If this assembly is compact, the load transmitted by contact with the head rest will be evenly distributed to the helmet. Localized forces are to be avoided to any portion of the helmet. The design of the cathode ray



One hundred fifteen subjects exposed to positive acceleration ($+G_z$) with a light array as shown in the diagram almost invariably lost the 80° light before loss of the light of 23° (23° LL). After completing the experiment it was decided to quantitate this in 30 subjects, and it was found that the 80° light loss (80° LL) occurred at a mean of 4.2 G_z, standard deviation ± 0.7 G; and in the same subjects, the 23° LL occurred at a mean of 4.5 G_z, S.D. ± 0.8 G. Central light loss (CLL) occurred at 5.3 G_z, ± 0.8 G.

This demonstrates also the reliability of the method used, since the original 115 subjects and the 30 subjects lost their 80° light at 4.24 G and 4.20 G respectively.

Comparison of 80° Light Loss, 23° Light Loss, and 0° Light Loss

	Symptoms			
	Clear	80° LL	23° LL	CLL
Mean (G_z level)	3.8	4.2	4.5	5.3
Range (G_z level)	2.3-5.1	2.7-5.7	2.9-6.4	3.6-7.0
Standard Deviation	0.7	0.7	0.8	0.8
Duration of symptom - Mean (sec)		5.4	5.1	6.8
Duration of symptom - Range (sec)		1.9-17.0	1.9-11.9	2.1-23.4

Figure 10. Grayout Thresholds During +G

(After Chambers[72], adapted from Zarriello et al[698])

assembly should be such that the unit is faired into the helmet contour so that in the event of sudden contact with the head rest the force will not be localized.

The location of the helmet electronic cable, its attachment to the aircraft, and the electrical disconnect are important considerations. The high voltages in the cable and its quick disconnect present problems in safety. In the event of seat ejection, the connection must be broken quickly, not relying on a pilot disconnect.

EQUIPMENT REQUIREMENTS

The purpose of the equipment requirements study was to identify IHMS/D design requirements imposed by the aircraft and mission, and crew capabilities and limitations. The major classes of considerations are:

- Crew anthropometric characteristics
- Crew visual characteristics
- Display data accuracy
- Display information format

The IHMS/D design has evolved from studies of the concept that a combat pilot should be able to operate his weapon system fully without being forced to remove his concentration from the target. These study reports have been reviewed to define some preliminary design requirements.

The anthropometric survey data interpreted in a previous subsection, describe the pilot population for the IHMS/D design. Honeywell's design will fit the 1-percentile to 99-percentile pilot population range. A design problem was to establish one eye reference point for locating the system optics on the helmet. On the basis of the anthropometric data available, the recommended design reference is shown in Figure 4. It defines the optics adjustment requirement envelope.

Personal Adjustment

The pilot's image adjustment capability will be within 0.25-inch square centered on the normal fitted eye location, eye exit pupil, of the individual. This capability will be provided for both custom-fitted helmets and the standard helmets.

Current helmets have deficiencies. Improper fitting and excessively resilient padding produce a marked decrement in retention, comfort, sound attenuation, and visibility in the upper vertical plane. The pilot will from time to time in a mission make adjustments to his helmet for improved comfort and/or to compensate for padding set. This will change the position of the projected image in the exit pupil of the eye. Therefore, vernier adjustment capability of the projected image will be provided.

Major adjustment capability will be available to the personal equipment technician. The IHMS/D will be adjusted to fit the individual by the personal equipment technician. These adjustments will be made and locked. Only vernier adjustment will be made by the pilot.

Visual Characteristics

The using population will have normal vision. For this design, normal vision is defined as 20/20 vision or better visual acuity with or without spectacles.

In the design of the IHMS/D it was necessary to consider whether the object will be in the center of the visual field (so that the image falls on the fovea) or to what extent it will be away from the center. The design objective was to have the image in the center of the visual field. The fisual field is defined as that part of the space that can be seen when the head and eyes are motionless. The visual field in two-eyed vision is the binocular field; the visual

field in one-eyed vision is the monocular field. The visual characteristics described herein are based on the information in Reference 7.

The visual field is limited by the dimensions of the functional retina and the shape of the cornea, and still further by nose, eyebrows, cheekbones, and other facial features.

For the monocular field, the boundaries of the field of an eye at rest are described by Figure 11. The IHMS/D design shall not obstruct this visual field. Because the cornea bulges, light from somewhat "abaft the beam" will strike it. Furthermore, light as much as 104 degrees from the optical axis will be refracted enough by the cornea and lens to strike a sensitive part of the retina (Figure 12). (This angle varies with the location of retinal receptors among individuals.) On a field-of-vision chart this 104-degree limit would appear as a circle of 104-degree radius, with its center at the fixation point of the eye.

When both eyes fixate the same point, their visual fields overlap in the center. This area of overlap -- of true binocular vision -- is shown in Figure 13.

Figure 14 maps the relative acuity (ability to see detail) for one-eyed daytime vision in various parts of the visual field. The best vision is within a small ring at the center of the field. Under favorable conditions, thresholds of less than 0.5 $\widehat{\text{min}}$ have been found in this area. The figures on the larger rings show how many times larger an object must be to be seen clearly at that position than to be seen at the center of the field. Under daylight conditions visual acuity gets rapidly worse as an object progresses in any direction from the center toward the edge of the field. At 6 to 10 degrees out, an object must be about twice as large to be seen as one in the central area; at 20 to 30 degrees out, it must be about 10 times as large, etc.

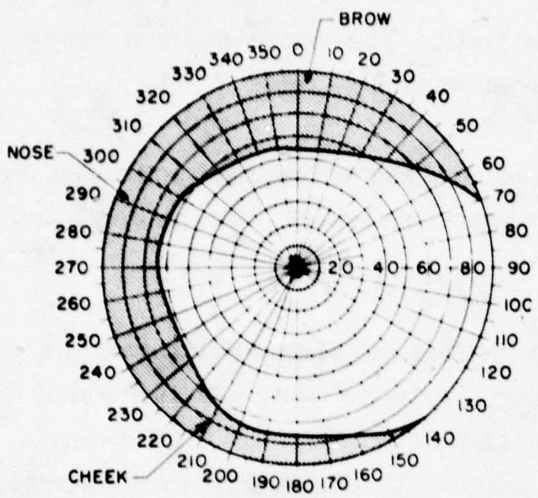


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Figure 11. Average Monocular Visual Field (Right Eye) (after Fulton[6-2], Fig. 269)

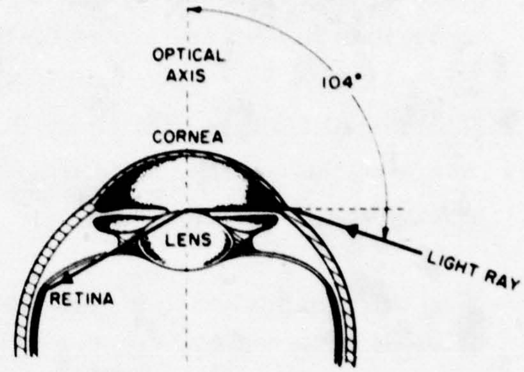

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Figure 12. How Light 104 Degrees From Optical Axis is Refracted to Strike Retina (after Pierenne[6-4], Fig. 17)

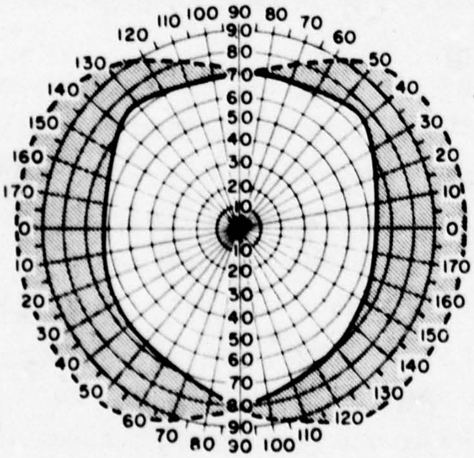

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Figure 13. Binocular Visual Field (from Duke-Elder[6-1], Fig. 981)

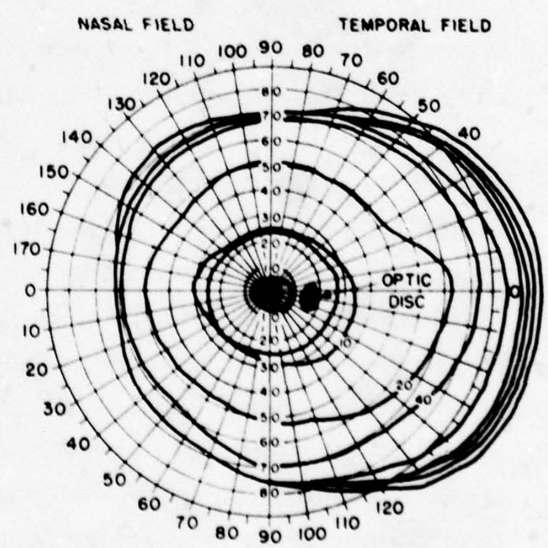

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Figure 14. Monocular Daylight Acuity Relative to Central Acuity (after Duke-Elder[6-1])

For this design, the design objective shall be for drawn symbology to subtend 20 minutes visual angle, minimum. This image size should satisfy reading requirements for all operational conditions.

Different parts of the eye are almost equally sensitive to light at daylight levels of illumination; a light seen out of the corner of the eye will look just as bright as when it is seen with central vision. This is not true, however, at night levels of illumination. At night, the center of the eye (the part used most in daylight) cannot see dim lights. As we go out from the center, the eye becomes more and more sensitive to dim light. Therefore, under low light levels, image resolution increases away from the fixation point.

The color of an object varies with its position in the visual field. At moderate levels of illumination, all colors appear as shades of gray at the edge of the field. A little farther in, a blue or yellow can be recognized, but only at positions near the center of the visual field can a red or green be observed. As seen in Figure 15, there is a fairly restricted region in the center of the field of vision where all colors are seen. Surrounding this zone is a second area in which no red or green is visible as such, but where blue and yellow can be recognized. Even blue and yellow fail toward the extreme edges of the field.

Display Data Accuracy and Other Factors

The IHMS/D unit will be used by fighter aircraft in the conduct of five basic missions:

- Air superiority
- Point intercept
- Close air support
- Counter air (interdiction)
- Reconnaissance and other noncombat activities

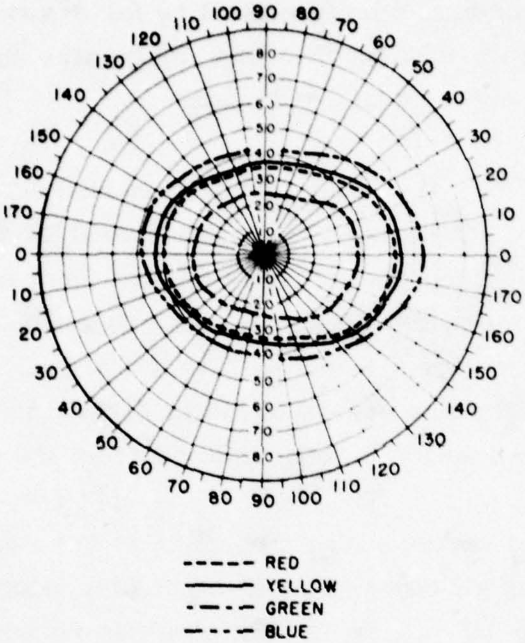

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Figure 15. Color Zones for the Right Eye in Moderate Illumination. Outside the ring for a given color, an object reflecting that color will appear gray.

These missions involve nine operations common to all five missions. These are identified in Table 1. Of these, the air-to-air combat operation (involving such tactics as the standard barrel roll attack and high-speed yo-yo maneuver) will pose the most severe stresses the IHMS/D unit will be required to endure. This operation will also create the greatest demand for a fast-responding, easy-to-read, high-accuracy display system. This can be achieved by optimizing such factors as:

- Display data accuracy
- Display information format
- Control response requirements
- Sensor information content
- Roll axis requirements

These factors and requirements which must be met to place them in an optimal state are described as follows.

Table 1. Operation Commonality Showing Fixed Wing Fighter Aircraft Activities Requiring Use of the IHMS/D

Mission Operation	Air Superiority	Point Intercept	Close Air Support	Counter Air	Recce
Warmup and takeoff	X	X	X	X	X
Climb	X	X	X	X	X
Rendezvous	X	X	X	X	X
Cruise	X	X	X	X	X
Air-to-air combat	X	X		X	
Air-to-ground combat			X	X	
Bomb damage assessment			X	X	X
Descent prior to landing	X	X	X	X	X
Landing	X	X	X	X	X

Display Data Accuracy

Display data accuracy is a function of the accuracy of the input data. For example, in the tracking mode, errors accumulate due to:

- Canopy distortion: 14 $\widehat{\text{min}}$ horizontal and vertical
- Windscreen distortion: 4.0 $\widehat{\text{min}}$ horizontal
  2.5 $\widehat{\text{min}}$ vertical
- Basic IHMS capability (CEP limitation): Classified
- Alignment problems (HMS/LOS): <30 $\widehat{\text{min}}$
- Helmet bias distortion (due to high g): <39 $\widehat{\text{min}}$
- Pilot errors (e.g., tracking target centroid instead of tailpipe): 12 $\widehat{\text{min}}$ (at 3000-foot range)
- Radial angle-off-boresight (errors increase with increase in angle)

Accuracy requirements for these and other related factors are as follows.

In the air-to-air combat role the pilot will perform the flight path management task and the visual search task for the targets by viewing the CRT display projected onto the IHMS/D visor. The literature identifies 10 variables or factors which are significant in terms of the observer's performance. They are:

- Target size: 20 $\widehat{\text{min}}$
- Target-background contrast: 100 percent
- Display resolution: 15 raster lines per symbol
- Display signal-to-noise ratio: 4.0 to 5.0
- Target location in search field: ≤ 50 percent display radius
- Scene complexity/confusing objects: 8 or fewer symbols

- Target time in view in search field: angular rate 20 degree/second or less
- Target rate of motion across the field: <20 degree/second
- Observer training and briefing: a search strategy must be developed
- Display scale factor: adjustable 1/1 to 20/1

The first six variables are related to target characteristics and the target environment. The last four should be considered in the display design for real-time search task.

Target size has been studied extensively in the laboratory to evaluate the observer's performance. Depending on the environment conditions of the experiment, target recognition occurs for targets that subtend minimum visual angles that range from 1.5 to 30 min. MIL-STD-1472A specifies the signal size for a CRT in an operational environment. "When a target of complex shape is to be distinguished from a nontarget shape that is also complex, the target signal shall subtend no less than 20 minutes of visual angle."

Contrast and luminance are not easily separable. It has been determined by Kelly that against a 10,000 foot lambert background (sky) condition, a 1000-foot lambert display luminance reflected from a clear combiner is quite marginal. Under these conditions it is estimated that 1800 to 3500 foot-lamberts of display luminance would be necessary at the pilot's eye for comfortable viewing. With a trichroic coated combiner, Kelly found that an equally comfortable display luminance was provided by delivering 840 to 1200 foot-lamberts to the pilot's eye. However, in this experiment the combiner reflected 25 percent of the CRT luminance and 63 percent of the background light. A number of methods for specifying contrast are available and are used by various authors. The data indicated that contrast has its primary influence

on target detection rather than recognition and that the direction of target/background contrast is not significant. One method should be used for specifying contrast. The recommended formula is:

$$C = \frac{L_h - L_1}{L_1}$$

where

L_h = high luminance

L_1 = low luminance

C = contrast

Multiply by 100 to express C as a percentage.

The human performance penalties to be paid for violating resolution requirements are generally not well documented in the literature. Resolution can be broadly defined as a measure of ability to delineate detail or to distinguish between equal values of a quantity. Electro-optical display resolution may be divided into the following broad categories:

- Display generation constraints such as field of view, display size, viewing distance, sensor and system component limitation, the resolving power of the eye, and special weapon delivery requirements.

- Recognition of ground objects

- Alphanumeric symbol generation, such as symbol size and raster lines per character

- Multisensor display consideration, superimposed displays on one monitor

- Line written displays

It is evident that a single resolution value cannot be specified as the standard across all display types and display uses.

Resolution requirements for electro-optical displays must be specified in terms of the considerations of the entire system. A general rule-of-thumb is that display resolution should be twice the most stringent sensor resolution requirements. For raster display which provides only stylized or synthetically generated symbols, 500 lines are generally accepted as a suitable resolution. If multisensor capability and LLLTV are anticipated, resolution as high as 1000 lines may be required. For raster displays, 10 raster lines per symbol height is required for recognition of a 15 $\overset{\frown}{\text{min}}$ symbol. Line width should be 3 $\overset{\frown}{\text{min}}$.

Beam noise on an imaging display has an effect of distorting contrast boundaries in an image and generally reducing image quality. Schaefer estimates a requirement for a display signal-to-noise ratio of between 4.0 and 5.0 to ensure a high probability of target detection. However, for "live" noise such as that which is common to CRT imaging displays, the observer may be expected to visually filter a portion of the noise component to effectively increase the display signal-to-noise ratio. The degrading influence of display noise should be evaluated under controlled experimental conditions.

In searching a vertically moving scene, target detection has been found to be lower for targets laterally displayed from field center. Search in a complex field yields results that indicate a linear decrease in probability of target detection as a function of target distance from display center. The slope of this function increased as field velocity increased from 5 degree/second,

suggesting a greater degree of concentration on the center of the search field as viewing time is reduced. A similar study involving a static field search task found that targets positioned midway between display center and perimeter were found most quickly.

Numerous laboratory studies have been performed to evaluate the effects of image clutter on confusing objects. The relationship between number of forms (N) and search time (T), in terms of percent correct recognition, was approximately constant ($N/T \approx C$). The existing data must be used with care when defining the number of confusing objects in the viewed scenes. No more than eight different symbols should be presented on the display at one time.

The time available to an observer searching for a target is an important factor in determining target search success. Although the rate of target motion relative to an observer limits available search time, target velocity itself may be a degrading effect on observers' performance. Dynamic visual acuity begins decreasing at a target angular velocity of approximately 20 deg/second. In tasks requiring detection of moving alphanumeric targets with search time held constant, performance was degraded in the range from 8.25 to 16 degree/second. Flight tests indicate that the accuracy of the sighting can be expected to vary between a fraction of 1 degree and 4 degrees depending on target angular rate and target sighting angle. For any given target angular rate, the pilots had smaller sighting errors when the target was located ahead of their aircraft.

The initial selection of display scale factors should be influenced by knowledge of the minimum angular subtense requirements for targets of interest. This scale factor should yield target sizes sufficient to ensure detection and recognition, while also maximizing target time in view and ground-area coverage. Laboratory data indicate that scale factor does not influence performance if all targets of interest are above threshold size at the largest scale factor. These results indicate that a maximum display scale factor should therefore

be selected, consistent with target sizes of interest, to increase sensor ground coverage area and minimize target velocity across the display. In air-to-air missions the display must be compatible with guns and missiles. Therefore, the scale should be selectable from one $\widehat{\text{min}}$ display = one $\widehat{\text{min}}$ sensor to one $\widehat{\text{min}}$ display = 1/20 $\widehat{\text{min}}$ sensor.

Display Information Format and Control Response Requirements

The IHMS/Display is capable of providing an optimal set of video scenes as an aid to flying the aircraft, conducting various non-combat missions (e.g., reconnaissance), and performing the various fire-control operations needed to detect, identify, track, and destroy enemy aircraft in an air-to-air combat situation. The display presents CRT imagery to the helmet wearer as a collimated image overlaying an ambient scene as viewed through a partially reflecting visor which forms a part of the optical system. Visor display data are presented to one eye or the other as specified.

While the IHMS/Display is useful in many air operations,* it is currently (i.e., for the Mark I, Mod I prototype) being confined to the air-to-air combat role. In this role the HMS/D operates in the following modes:

- Radar search
- Radar acquisition
- Identify
- Medium range missile (MRM)
- Quick radar lock
- Short range missile (SRM)
- Gun firing

*Such as take off, climb, cruise, rendezvous, air-to-ground combat, landing.

Video scenes, symbology, control, and other requirements associated with each of these modes are summarized in Table 2. Display formats for each of these modes including requirements for each display element involved will be specified in later design iterations. Specific formats cannot be specified until after the majority of the system and operational requirements have been established and agreed to by AMRL.

Sensor Information Content

Sensors likely to be used on a typical fighter aircraft in an air-to-air combat situation include:

- Main radar (mechanically scanned)
- Long range telescope (E-O device)
- Rear warning device (IR)
- Radar Receiver (Broadband with directional antenna)
- Missile tracker (TV camera)
- Missile seekers
  - E-O
  - Semi-active radar
  - IR
  - Radar

Typical sensor characteristics including sensor input to CRT display (last column) are shown in Table 3. Sensor data display requirements for each type of sensor are as follows:

The establishment of information requirements is a complex exercise. Requirements must be developed by aircraft type and mission, the crew tasks, the available data sensing, the processing equipment, and the equipment constraints. In general, there is not complete agreement among cockpit

Table 2. Air-to-Air Combat Control and Display Requirements

Mode		Scene Display	HMS/D Generated Symbols Displayed	Equipment Controlled by Helmet Sight	Helmet Sight Information used to Compute:	HMS/D Controls Required	Other Conditions Established
Radar search		Radar Plot	None	None		Mode control.	Radar plot on helmet display via scan conversion.
Radar lock (distant)	Before lock	Radar Plot including gate symbol	None	Antenna position in azimuth. Range gate position.		Mode control Acquisition switch Radar antenna elevation	Radar plot on helmet display via scan conversion. Radar mode changed by mode control setting.
	After lock	None	Cues and range	None	Cue position	None	
Long-range identification		E-O tracker video including gate symbol	Radar cue Radar range (if radar is locked)	Tracker pointing (before lock)	Cue position Cue blanking	Mode control Acquisition switch	Radar may be pointed and locked at same time if previous lock is broken.
Medium range missile (semi-active)	Radar locked	None	Radar cue Radar range	None		Firing switch	Weapon selection
	Lock direction	Automatic switch to "quick radar lock" made					Firing switched to automatic range gate operation.
Quick radar lock		None	Sight reticle	Radar pointing in azimuth and elevation		Acquisition switch	Radar switched to automatic range gate operation.
Short-range missile (E-O)	Before lock	E-O tracker video including gate symbol	Radar cue Radar range (if radar is locked)	Missile tracker Radar pointing (if radar not locked)	Cue position Cue blanking	Acquisition switch Mode control	Weapon selection If radar is not locked acquisition switch locks missile tracker and radar at same time.
	After lock		Radar range	None		Firing switch	
Gun firing	Radar locked	None	Radar unlock warning Steering symbol	None	Stabilization of display in front of windshield.	Firing switch Mode control	Computer drive of steering symbol to provide lead compensation
	Radar unlocked	Pilot may switch to "quick radar lock" manually				Acquisition switch	

Table 3. Typical Sensor Characteristics

Sensor	Type	Range (nm)	Resolution	Active Field or Gimbal Limits	Instantaneous Field	Type Display
Main Radar	Mechanically scanned	>50	~2 deg	±60 deg	~2 deg	Range versus azimuth plot
Long-range Identification Device	Telescope and TV camera	5 to 15	Fine	Small compared with radar	Very small	Raster scan TV
Rear Warning Device	IR	5 to 15	Coarse	±60 deg cone about tail	±50 deg cone about tail	Discrete -- located by quadrant
Radar Receiver	Broadband with directional antenna	> 50	Coarse	4π steradian	4π steradian	Discrete -- located by quadrant
Electro-optical Missile Tracker	TV camera	~ 5	Medium	Less than radar	Several degrees	Raster scan TV

designers about the total information requirements per crew man per mission phase. However, there is general agreement that the following information should be displayed on a vertical situation display (the IHMS/D is a vertical situation display). It is noted that the information requirements detailed specification should also be in terms of the form of information, the source, the degree of processing required, and the manner of presentation (status versus command versus error).

- Roll and Pitch Angle (mandatory for all flight phases) - There is unanimous agreement among analysts and display designers on these items, whose importance is obvious. In addition to qualitative roll and pitch information, quantitative indication is needed for some aircraft and certain maneuvers, e.g., pitch angle control for weapon delivery or specific roll angles for procedural turns.

- Vertical Orientation (mandatory for all flight phases) - It is especially important in view of the use of E/O displays in all-weather and night situations and weapon delivery.

- Altitude (mandatory for all flight phases) - While there is general agreement on the importance of altitude information, some difference of opinion exists as to whether radar or barometric sources should be used at low altitudes.

- Airspeed (Mandatory for all flight phases) - Nearly all the analytic studies list airspeed as a requirement, but only about half of the displays examined here actually present this information. The importance of this item seems intuitively obvious.

- Steering (Mandatory for all flight phases) - All contemporary displays present some form of steering information for all flight phases. In most cases steering is presented as command information relating to the horizontal component of the aircraft flight path. In a few cases the vertical component is presented as well.

- Glideslope and Glidepath (Mandatory for landing) - This is actually a form of steering information, where glideslope refers to the vertical component of the flight path with respect to the landing site and glidepath refers to the horizontal component. The form of the information and the nature of the presentation are partly dependent on the kind of on-board or external guidance system available.

- Angle of Attack (Mandatory for landing, desirable for takeoff) - The rating of this requirement is subject to qualification. The importance of this parameter display depends upon its importance in controlling the particular aircraft.

- Hover Position (Mandatory for landing, optional for takeoff) - This requirement applies to rotary-wing and V/STOL aircraft.

- Hover Groundspeed (Mandatory for landing, optional for takeoff)- The requirement applies to rotary-wing and V/STOL aircraft only.

- Lateral Ground Velocity (Mandatory for landing, optional for takeoff) - The requirement applies to rotary-wing and V/STOL aircraft only.

- Pitch Trim (Desirable for en route and landing, optional for takeoff) - For displays which are non-flight path centered, it is probably more important than the data indicate, since it affords a convenient and simple way of using the display horizon line as a level flight reference during cruise at varying conditions of pitch trim.

- Vertical Velocity (Desirable for all flight phases) - Vertical velocity information is extremely useful during climbout for monitoring climb schedule and anticipating level-off at cruising altitude. Apart from its use en route whenever altitude changes must be made, vertical velocity information is valuable for altitude holding since it is a more sensitive index of performance than altitude alone. It is of particular importance for descent from altitude, approach, and landing, where it may even deserve mandatory status.

- Velocity Vector (Desirable for en route and landing, optional for takeoff) - For flight-path centered displays, velocity vector information is mandatory; for pitch displays it is less important although obviously still useful as an indicator of aircraft performance in the vertical situation plane.

- Heading (Desirable for all flight phases) - This item should not be confused with steering. Heading refers to a status indication of the direction of the longitudinal axis with respect to north (either true or magnetic); steering implies a command indication. The importance of heading will vary somewhat with the quality of steering information available and with the need for north reference on the VSD during the mission. If there is also a horizontal situation display in the cockpit, the importance of heading on the VSD may diminish.

- Turn Rate (Desirable for landing, optional for en route) - This information is very useful in approach and landing for making procedure turns under air traffic control. This information is included on modern flight directors.

- Sideslip (Optional for en route and landing) - It is desirable aid for procedure turns. Available in flight director display.

- Pull-up (Optional for en route and landing) - This is an optional item for most aircraft. However, if the mission of the aircraft entails terrain avoidance or terrain following, it becomes a mandatory requirement. It becomes mandatory for air-to-ground missions.

- Range to Go (Optional for en route and landing) - This is more properly an HSD information requirement. However, for certain tactical applications it may be useful to present range information in combination with a display of the vertical situation accurate range-sensing equipment.

- Runway Heading Error (Not required) - There is virtually no support for this as a takeoff requirement.

- Groundspeed (Not required) - For fixed wing aircraft this appears to be a requirement more appropriate for HSDs than for VSDs. It may be a requirement for rotary-wing and V/STOL aircraft.

- Pathway (Not required) - It seems more appropriate to display this information on an HSD in conjunction with other elements of the horizontal situation.

Roll Axis Sensing and Stabilization

In vertical situation displays the basic dimensions are azimuth and elevation. Lateral displacement of display elements signifies change in aircraft heading. Vertical translation of display elements represents change in pitch attitude of the aircraft. Rotation of the display elements denote movement of the aircraft about its roll axis. As a picture sensor for IHMS/D increases its off axis view, its projected picture rotates, which gives the pilot the wrong cue.

The IHMS/D will be an inside out display. It will have a fly-to format. This means that as the aircraft rolls right the horizon projected on the display it appears to roll left. If a roll angle pointer symbol is drawn on the display, it will be placed at the top of the display format. The proper corrective action for right roll attitude is to roll the aircraft counterclockwise, which is to fly to the roll pointer position. Consistency of display dynamics is most important for display acceptance by using population.

Two methods exist for roll attitude sensing for the helmet. One method uses the two aft photo sensors on the helmet. Another method uses three photo sensors on each side of the helmet.

The present solution uses the two aft photo sensors. It represents a modification of the existing software program. This method gives 1-degree roll attitude resolution of the picture. It will give this resolution in the following envelope :

- Roll ±20 degrees
- Azimuth ±10 degrees
- Elevation +5 degrees

With three photo sensors on each side of the helmet, a new software package must be developed. This method gives several degree roll attitude resolution of the picture. Its advantage is that a roll solution can be generated over a much larger azimuth field of view, ±50 degrees.

The preliminary roll requirements data were collected as shown by Figures 16 and 17. Figure 16 describes the envelope of a test helmet with camera in our cockpit mockup. Figure 17 describes the envelope of a helmet sight system in a F-106 cockpit with the modified canopy. These data need to be collected for the cockpits of all aircraft for IHMS/D application.

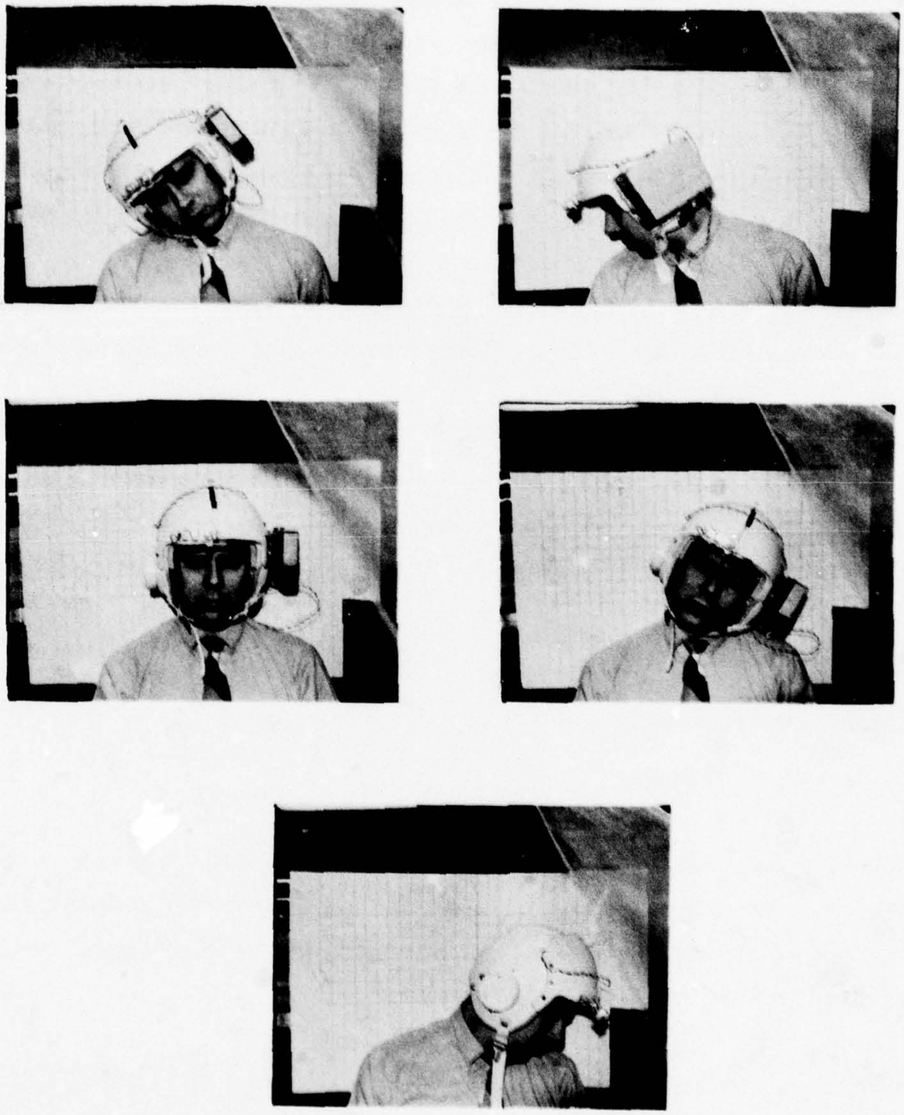

Figure 16. Mockup Roll Data Collection

Figure 17. F-106 Roll Data Collection

Given that roll stabilization is required, what is the roll capability of the head for various line of sight angles? The roll attitude envelope developed by these data represents a "comfortable" maximum roll for given line of sight angles. Head roll envelope data have been collected by J. D. Grossman of crewmen in an F-4J. Grossman's data documented the "farthest limits of each subject's several passes"; each subject looked to his limits.

The measurements for this report were taken on one subject. The helmet line of sight fixture was used. This fixture was a balanced assembly, weight at 3.95 pounds. The line of sight projector is powered by four AA size cells. It projects the bulb filament as the reticle which is held on the target by the subject as he changed head roll attitude maximum left roll to maximum right roll about the line of sight. The targets were located on a 10-foot radius sphere as shown in Figure 18.

Table 4 describes the combination of angles for a line of sight and the order of the measurements. A plumb bob line was used as the vertical reference. The subject's pupils were used as the head roll reference with respect to the vertical reference. The subject was seated centered in the sphere with his nasal root at the center of the sphere. All targets were to the left of the subject. Photographs were taken of the subject's head in such a manner that the pupils and the vertical reference were visible in each picture.

The subject viewed each target from a natural sitting position simulating a seat belt restraint. The camera location was maintained with respect to the subject to record head position for each roll position for a given line of sight. All 90 degree elevation positions and the 120 degree azimuth positions at 30-degree and 60-degree elevations angles were beyond the line of sight capability of the subject. The zero roll position of the head did not always yield a 90-degree angle between the pupils and the vertical. The camera had to be offset from the line of sight and, therefore, caused some distortion in the picture. The roll angle was determined from the reference zero for all angle reading.

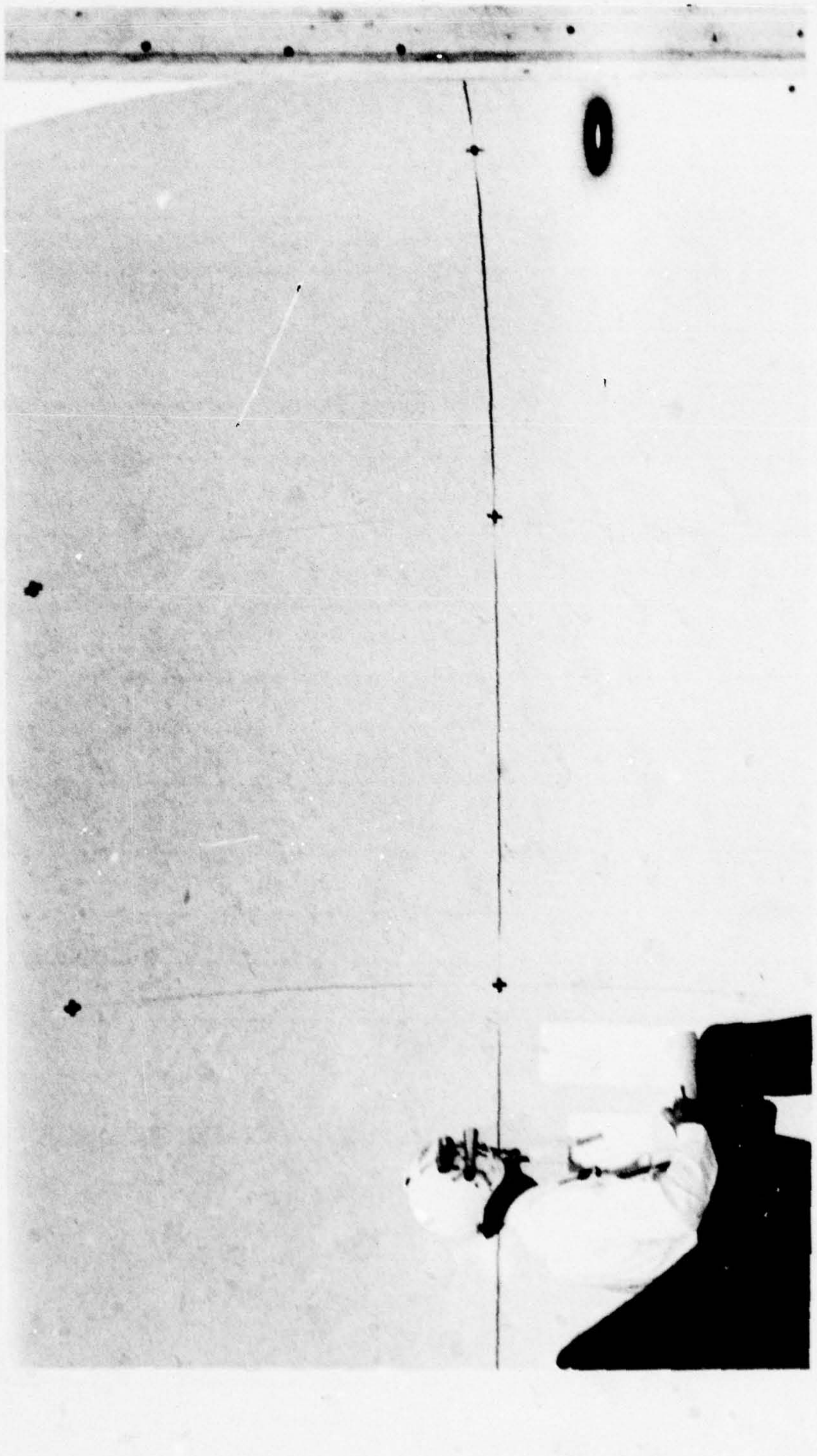

Figure 18. Target Fixture

Table 4. Head Roll Attitude versus Elevation Angle versus Azimuth Angle

Azimuth Angle	Head Roll Attitude	Elevation Angle												
		-30 degrees			0 degree			30 degrees			60 degrees			90 degrees
		#	$\angle$	$\Delta\angle$	#	$\angle$	$\Delta\angle$	#	$\angle$	$\Delta\angle$	#	$\angle$	$\Delta\angle$	#
0	Zero	1	86	0	16	80	0	31	82	0	46	88	0	61
	Left	2	132	446	17	122	22	32	107	23	47	96	8	62
	Right	3	40	46	18	36	44	33	59	25	48	69	19	63
30	Zero	4	91	46	19	90	0	34	90	0	49	85	0	64
	Left	4	121	30	20	124	34	35	107	17	50	98	1	65
	Right	6	34	57	21	44	46	36	53	37	51	73	12	66
60	Zero	7	93	0	22	92	0	37	87	0	52	86	0	67
	Left	8	119	26	23	123	31	38	103	16	53	98	8	68
	Right	9	56	37	24	53	39	39	73	14	54	82	4	69
90	Zero	10	89	0	25	97	0	40	98	0	55	90	0	70
	Left	11	123	34	26	121	24	41	108	10	56	99	9	71
	Right	12	70	29	27	63	34	42	89	9	57	86	4	72
120	Zero	13	75	0	28	99	0	43			58			73
	Left	14	100	25	29	115	16	44			59			74
	Right	15	60	15	30	78	21	45			60			75

Table 4 describes the degree of roll angle for each condition. Figure 19 describes right roll around the line of sight. Figure 20 describes left roll around the line of sight. Figure 21 describes roll angles versus elevation angles. Note that roll into the direction of the azimuth angle is less than the roll away from the azimuth angle.

SAFETY

The helmet's primary function is to protect the pilot's head from major or fatal injury within the flight regime of any aircraft in the USAF inventory. The helmet's protective capability must not be decreased because of the IHMS/D system. The IHMS/D is truly a man/machine system. One of the IHMS/D design objectives must be to optimize the man/machine interface.

Weight and Balance

A specific problem is to develop a weight and weight distribution envelope as described by Figure 22. However, within the scope of this study we have not quantified the delta weight. The second- and third-hand reports of pilot's comments to the weight added to helmets for a helmet sight system, VTAS, indicate that these pilots are sensitive to increased helmet weight. The weight problems have at least two limit conditions.

- From the design point of view, at what weight/weight distribution does the pilot's tracking performance deteriorate?
- From the operation point of view, at what weight/weight distribution does the pilot fatigue and discomfort set in?

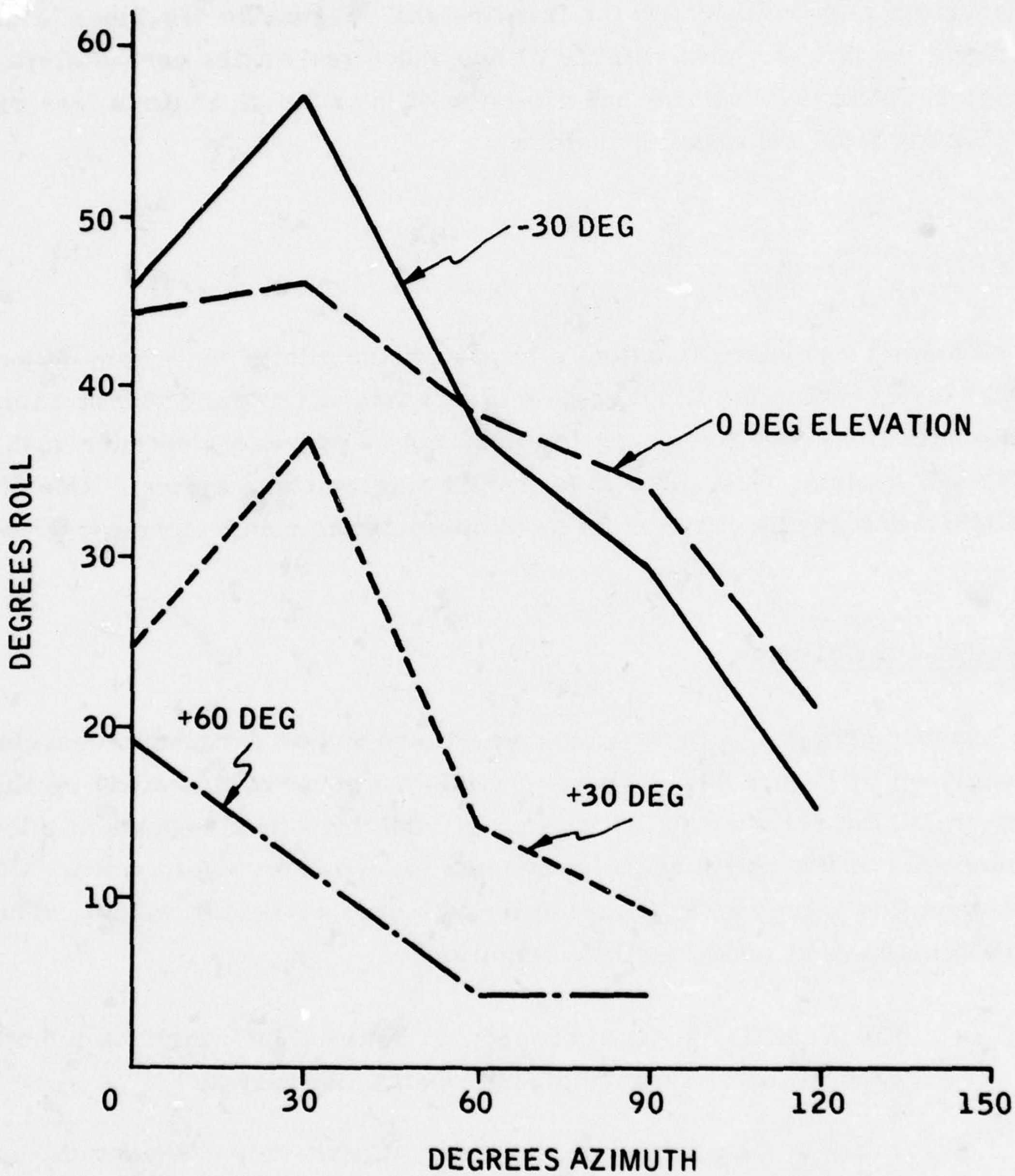

Figure 19. Head Right Roll Around Line of Sight versus Azimuth versus Elevation LOS

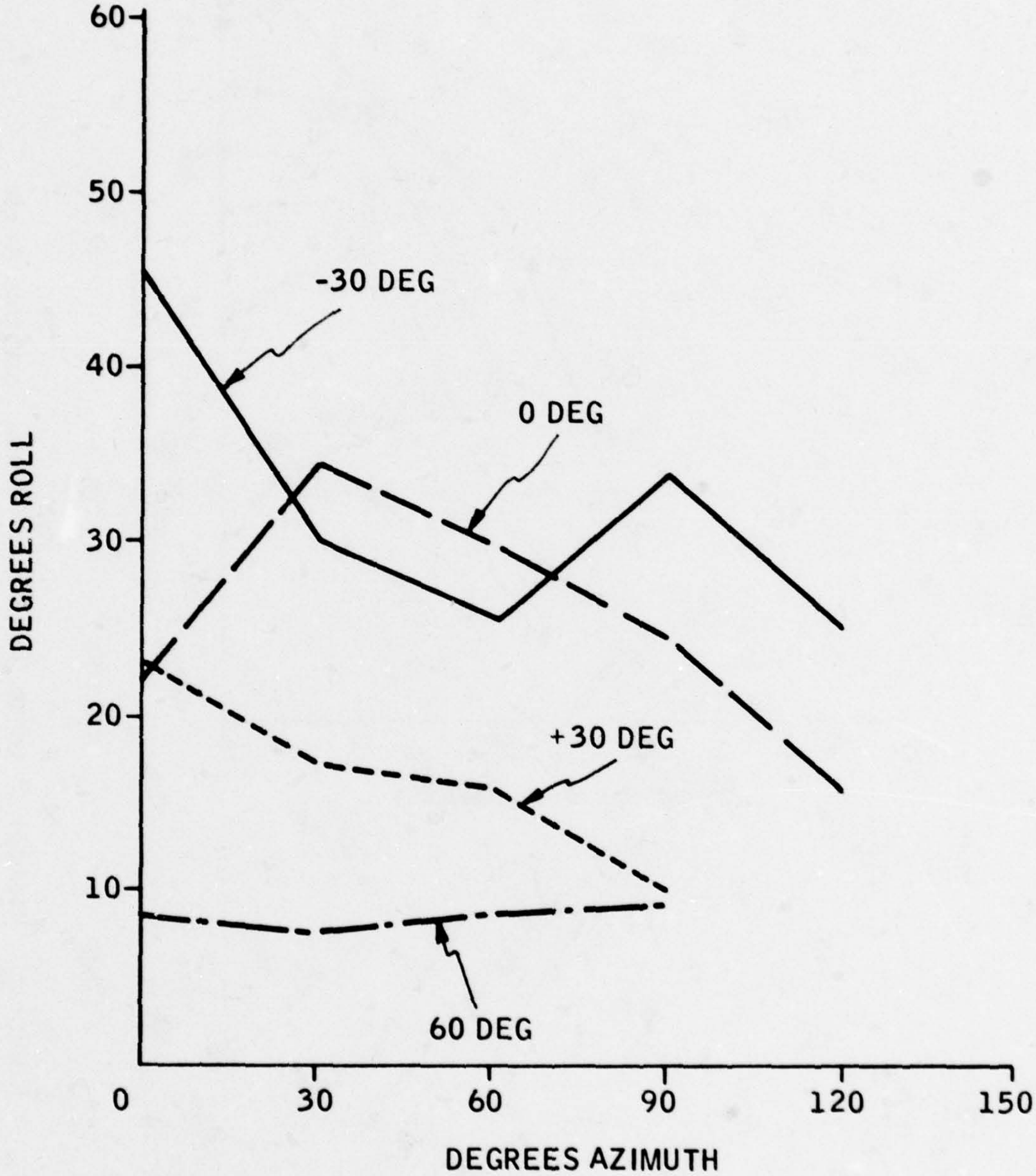

Figure 20. Head Left Roll Around Line of Sight versus Azimuth versus Elevation of LOS

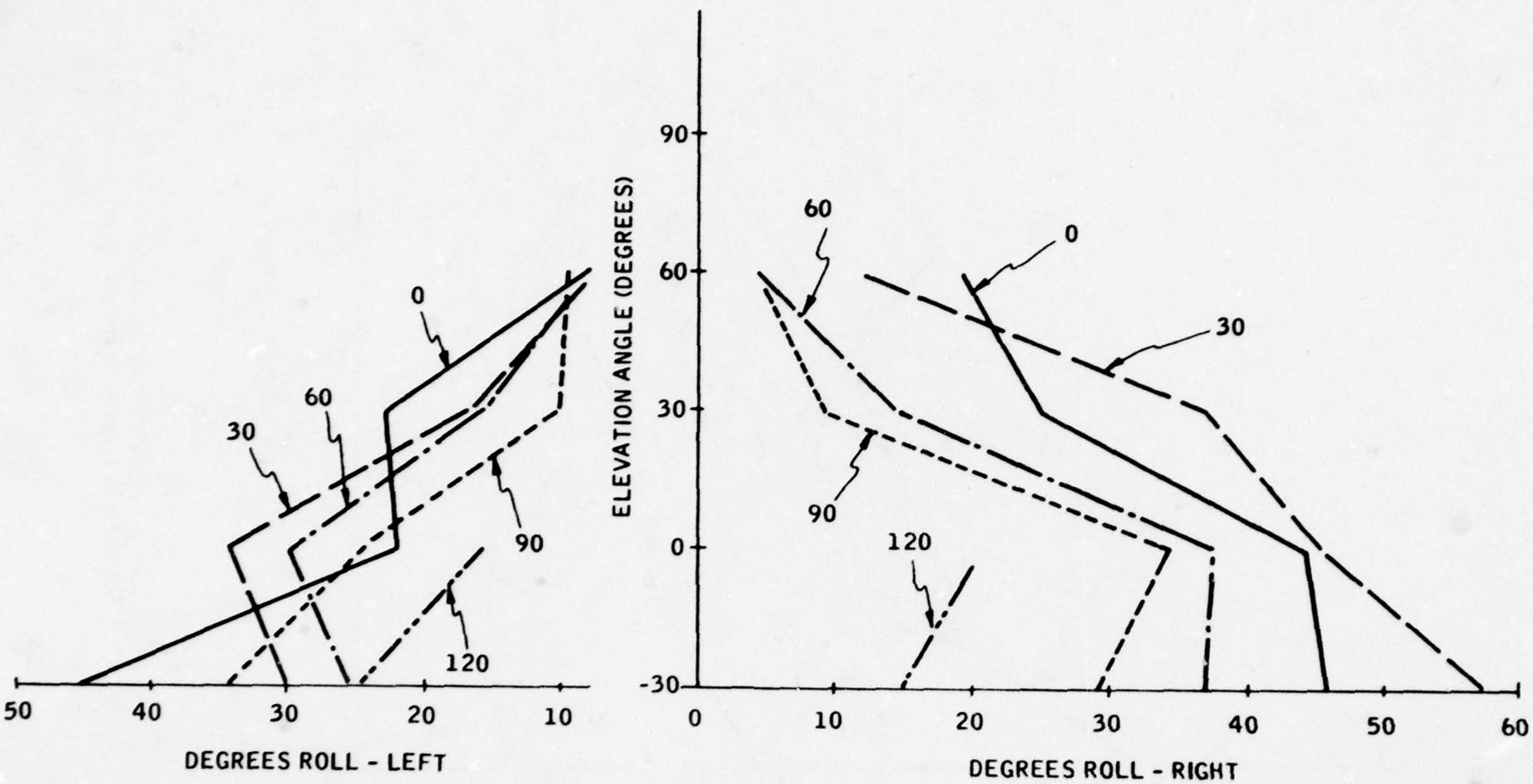

Figure 21. Head Roll Angle Capability versus Elevation Angle

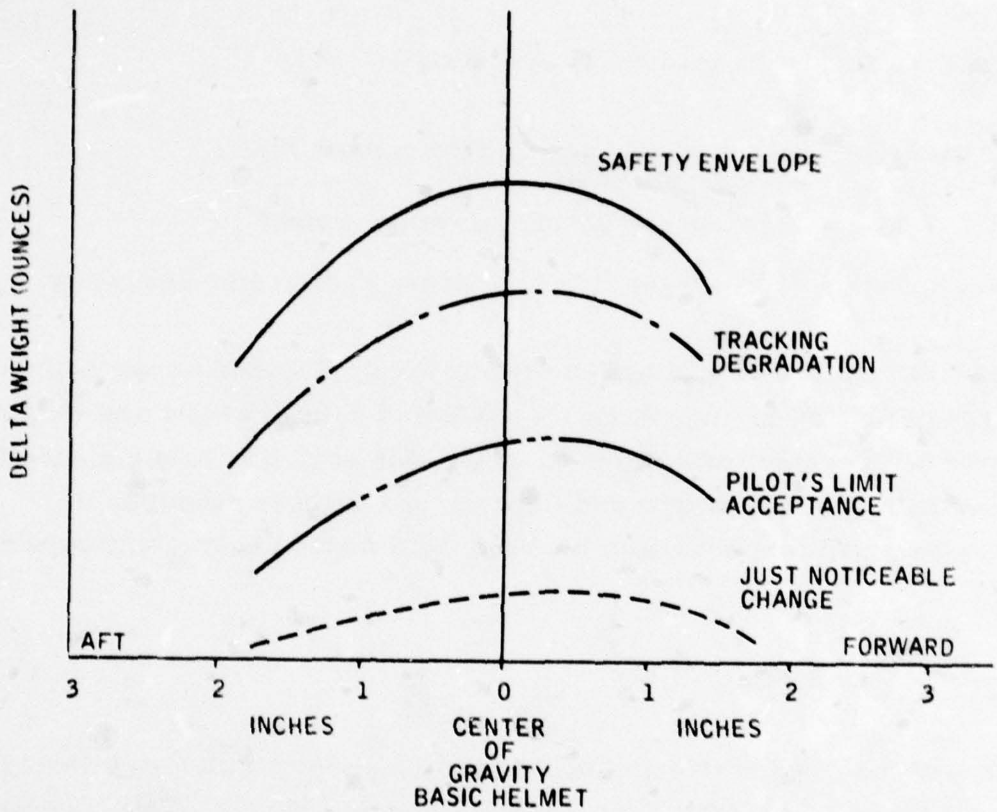

Figure 22. Helmet Weight/Weight Distribution Envelope Concept

In addition to these limit considerations, the general problem is the weight and movement of the helmet on the head in the operation environment. The result of simple calculations indicate that the addition of 40 inch-ounces to the helmet in the pitch plane causes a center of gravity shift of ±0. 15 inch for the helmet-neck-head (HNH), ±0. 4 inch for the helmet only.

These calculations are based on the following:

4. 0 pounds =	helmet weight, large size custom liner, and oxygen mask
10. 5 pounds =	head/neck assembly, average weight
2. 5 pounds =	delta weight at 1 inch off the HNH center of gravity

The recent literature was reviewed to determine what studies are being or have been conducted to investigate the effects of helmet weight and weight distribution. The first consideration of the helmet is that it is a protective improvements from vibrations and impact. All of these concepts, if implemented, will interfere with the head/neck assembly tracking capability.

Current Helmet Situation

To gain increased understanding of the pilot's helmet problems, a Honeywell representative visited Dayton, Ohio, on 14 December 1972. The purpose was to take part in a coordination meeting with the Life Support System Project Office and AMRL representatives for the HMS/D helmet interface problems. The general meeting result was that Life Support System Project Office will critique the HMS/D design from the reference of the user safety versus user safety with the current standard Air Force helmet.

The Life Support System Project Office is concerned with the protection functions of the helmet. They are concerned that the IHMS/D

- Adds weight to the standard helmet
- Wires the pilot's head to high voltage
- Eccentrically loads the helmet such as to affect the exit pupil under vibration conditions
- Creates vision problems or degradation

The status of the "standard" Air Force helmet is described as follows:

1) The Life Support System Project Office is responsible for integration of head gear. The engineering responsibility for the HGU-2A/P helmet is at San Antonio, Logistics Command.

2) The Booz Allen Company has a contract to study helmet problems. The objective of the study is to develop specifications for the development of the next-generation helmet.

3) The Gentex Company has a study underway to reduce helmet shell weight, yet maintain the shell's protection functions.

4) The Life Support System Project Office sees a family of helmets, not more than three.

5) Head protection --

   - The Navy helmet test results will be reviewed by AMRL tests include wind blast and parachute opening shock. The chairman commented that the Air Force had never lost a helmet in a test, yet the helmet retention rate in seat ejections is 80 percent.

- Impact -- The helmet must absorb 64-foot pounds per MIL-H-26671B, dated 1 December 1966, with Amend. II, 18 October 1967.

- USAF is going to "Z" 90 Committee testing techniques This committee of experts, headed by Dr. Snively of the the Snell Foundation in California, has designed helmet tests for impact and penetration.

- The Army has done a study on protection implications for helmet visors. Fifty percent of Army Aviators' head injuries are to the face.

- Fort Rucker has an injury data bank.

- USAF aviator's neck injuries are due to buffeting, barrier landings, ejection, wind blast, and flailing; all of which will be made worse by HMD weight eccentricity, vibration frequency, and increased helmet weight.

6) Vision protection --

- The Air Force is supplying its pilots with dual-visor helmets.
  - Training command - all pilots have dual visors.
  - Tactical command - switching to dual visors.
  - SAC - switching on voluntary basis.

- There is a new polycarbonate visor spec: MIL-V-43511. Curvature is a problem. Scratches are a problem.

- The Air Force has lost several acrylic material visors at approximately 600 knots.

- The F-111 pilot's custom fit helmets have bird-strike protection capability.

7) Vibration protection --

- The head assembly has a natural frequency between 40 to 60 Hz.

- The head and helmet visor do not move together in vibration.

8) Fire and smoke protection --

9) Acoustic protection --

10) AMRL testing --

- Review testing of helmets by Navy.
- Vibration testing --
  - -- exit pupil effects
  - -- visual acuity effects
  - -- tracking capability
- Determine correlation between model and test results
- Wind blast? Testing will depend on Navy test results review.

11) The HMS/D should not compromise the primary mission -- training. Most of the time wearers of the HMS/D will be training.

12) Life Support System Project Office considers potential hazards as

- Electrical -- tolerances to shocks
- Mechanical -- ingress/egress problems
- Chemical -- toxics/irritants to the eye

13) Oxygen masks --

- MBU-5 mask is in the inventory.
- An integrated mask visor is scheduled for the late 1970's.
- There is a new bayonet fastener for the oxygen mask. This fastener has a flange that extends under the visor.
- Military specs allow the visor to be trimmed to fit individual masks.

14) Inflation collar

- This is being added to the F-4 pilot's personal equipment.

Mechanical Hazard Analysis

This analysis was undertaken to identify the mechanical hazards to which the IHMS/D will be subjected while being worn by an aircrewman. The overall objective of the IHMS/D design program "is to design, develop, and fabricate an IHMS/D that could be used efficiently and effectively in USAF visually coupled systems and whose end result would be a production release. This system shall permit the use of pilot/crew capability for aiming and tracking while simultaneously viewing information developed from airborne systems or remote sensors ... the program shall be directed towards producing a flightworthy system which is acceptable to operational personnel."

The human senses of comfort, visibility, and hearing must be served in modern flight. Helmet designs which compromise these senses will be ineffective and may cause pilot reluctance to wear the helmet. Pilots wear helmets for:

- Protection: visual, thermal, impact, ballistic, and acoustic.
- A base for mounting required equipment: oxygen, communication, and VCS.

The Life Support System Project Office represents the interest of the operational personnel. Systems that become acceptable to the Life Support Systems Project Office usually become acceptable to operational personnel. One goal for IHMS/D designers is to maintain the protection function of the basic helmets while adding the IHMS/D function.

MIL-STD-1472A specifies a general requirement for design consideration of hazards and safety factors. "As a part of system equipment design, safety factors shall be given major consideration, including, as a minimum, the effective application of the human engineering criteria in other sections of this standard, together with the representative safety criteria herein." The detail requirements of MIL-STD-1472A for safety design cannot be directly applied to the HMD design. Therefore, the checklists for mechanical hazards from Woodson's Human Engineering Guide (Ref. 8) was adapted to help identify the IHMS/D problems.

The implied task of designers is to create designs which do not lead to accidents, personal injury, or damage to equipment. Also, safety must be everybody's business and concern to ensure a successful system design.

The two primary mechanical hazards for the pilot, wearing the IHMS/D, are ejection and crash landings. The design implication of these hazards for the IHMS/D is to ensure that the IHMS/D design does not degrade the protection functions offered by the standard HGU-2A/P for these hazards. A secondary design implication is that the IHMS/D shall be designed to resist all forces and remain functional.

For head protection from impacts, the IHMS/D design goal is to provide protection to the brain via the helmet so that the subject remains conscious after the survivable crash. It is recommended that the maximum head deceleration be 300 g with 250 g as the design goal for the impact energies specified in the latest amendments to ANSI Z90.1 (Ref. 9). The test fixture used to measure helmet protection function for impact blows should have the following characteristics:

- The drop fixture with the head mounted shall weigh 11.0 ±0.2 pounds.
- The helmet assembly is extra
- The specified impact energy is for the drop fixture head form
- The drop fixture shall be very stiff. It should be constructed per the instructions of ANSI Z90.1.

All the mechanical hazards identified produce dynamic loads on the helmet. The IHMS/D components must absorb energy in each of these hazards. To evaluate each hazard, the estimated energy absorbed was calculated into units of work (foot pounds). Work, of force, is the product of the force and the effective displacement of its application point. The energy of a body is the amount of work it can do (by virtue of its motion or position) against forces applied to it. In most hazardous situations, the IHMS/D has kinetic energy, and is accelerated or decelerated. The total work of applied forces acting on any body equals the change in the kinetic energy of the body. Work done = KE in translation = $1/2\ m\ (v_2^2 - v_1^2)$, where v_2 is final velocity and v_1 is initial velocity. Where possible, each hazard was defined in terms of work done on the IHMS/D assembly and/or its components.

A typical mission in terms of IHMS/D preflight checkout and operations is as follows:

- Go to the aircraft
- Enter the aircraft
- Attach personal equipment leads
- Checkout IHMS/D as an aircraft subsystem
- Takeoff - flight path management tasks
- Cruise - flight path management tasks
- Attack - mission management tasks
- Cruise - flight path management tasks
- Landing - flight path management tasks
- Disconnect personal equipment leads
- Exit from the aircraft
- Depart from the hard stand area

Possible mechanical hazards related to the pilot, and/or the mission, and/or the IHMS/D due to the IHMS/D being in the system are as follows:

Entry into the cockpit - snagging

Ejection - Wind blast
Rotation
Accelerations/decelerations
Personal leads disconnect

Impact - Head protection
Face protection

Ballistic - Face protection

Buffet in cockpit

Head motion for normal operations

Adjustments requirements in the cockpit

Slippage on the head

Noise, protection

Vision, protection

Exit from cockpit

A safety checklist for design considerations for mechanical hazards factors follows; each item of this checklist is discussed in terms of a typical mission.

1) Stumbling or tripping or slipping
2) Bumping the head
3) Explosion/implosion
4) Snagging
5) Electric hazards
6) Burns
7) Pinching or mashing
8) Noise
9) Falling
10) Acceleration
11) Temperature and pressure
12) Bright light
13) Toxic substances
14) Physical strain
15) Radiation
16) Wind blast
17) Impact
18) Ballistic

The following paragraphs discuss the standard considerations for design for safety. Each consideration is reviewed for its applicability to the IHMS/D design. The identified hazards produce dynamic loads which have been converted to work (foot pounds) that the IHMS/D should perform.

1) Stumbling, tripping, or slipping

   This type of hazard would not be caused by the helmet. A crewman wearing the helmet may meet this hazard and cause damage to the IHMS/D. Assuming that the head helmet assembly weighs 15 pounds, the work done by any component stopping this assembly during a fall will be 100 foot pounds. If the crewman drops the helmet from his side due to a stumble or slip, the work done by any component stopping this assembly will be 16 foot-pounds.

2) Bumping the head

   This type of hazard exists due to the crewman straightening up while wearing the helmet. The torso is moving with the velocity of the head at two feet per second. There is a high probability that the head will strike a hard edge surface with a 0.032 radius. Assuming 65 percent of the body weight is above the hip, and assuming 210 pounds body weight, the work done by any helmet component stopping this movement will be 8 foot/pounds.

3) Explosion

   Explosion hazards for IHMS/D are in two categories. One category is the explosion/implosion of the CRT. What happens to the glass and tube internal components? Is there a direct path into the crewman's eye for this debris? Our designers feel that the hazard is minimum in our Model 7A small-diameter tube. There will not be a rebound of the glass.

The Air Force does not require an implosion test to qualify the CRT tube. If our Model 8 design places the CRT very close to the eye and inside the visor, a test is recommended to implode a CRT tube in its helmet mount with the visor and count the distribution of glass particles on the subject's (dummy's) face.

The second potential explosion hazard is in a crash landing where the cockpit is filled with an explosive air mixture. The crewmen must be rescued by themselves, by fellow crewmen, or by ground rescue teams. The power and signal cables to the IHMS/D must be disconnected. An explosion-proof, quick-disconnector is provided. This connector is mounted in the aircraft in such a manner to also provide IHMS/D cables disconnect for ejection from the aircraft or for very quick ground exit.

4) Snagging

Catching the IHMS/D personal leads ends upon entering or leaving the cockpit is a high probability of occurrence hazard. The personal leads must be loose to enable the pilot to make the hookup to the aircraft system. These loose leads will tend to catch if the pilot wears the helmet as he enters and leaves the cockpit. Assuming the work done by the personal leads in stopping upper body movement is 8 foot-pounds and assuming that the helmet is firmly attached to the head and assuming that the work is done over 0.5 inch, the force on the lead is 192 pounds.

5) Electric hazards

These are discussed in a separate analysis IHMS/D-MPR-6.

6) Burns

Burns represent a minor hazard. The potential may exist for the CRT to overheat. The bare hands touching the CRT fixture to adjust the helmet, could be burned if the CRT fixture is at or over 160°F.

7) Pinching or mashing

This is not a hazard with the IHMS/D.

8) Noise

The noise hazard exists. The IHMS/D does not introduce any new noise hazard. We must however, be careful that our design does not reduce the noise protection offered by the standard Air Force helmet. The IHMS/D noise protection capability can be evaluated on a subjective basis.

9) Falling

The hazards are the same as Item 1.

10) Acceleration

Accelerations are imposed on the IHMS/D by aircraft maneuvers, aircraft vibrations and ejection from the aircraft. The most severe acceleration will be due to ejection from the older model medium performance aircraft. The acceleration will be 20 g with the rate of onset of 250 g per second. The seat may rotate at 133 RPM immediately after seat separation from the

guide rails. This rotation rate will decrease very quickly. Ejection can occur up to 600 knots. For the crewman, assume C_D = 1.33, drag area = 6 ft^2 (Reference:Hoerner), ejected weight = 300 pounds; then, the initial deceleration will be 30 g.

Acceleration due to aircraft maneuvers will be 7 to 9 g with 7.33 g the maximum g for sustained maneuvers when the pilot is equipped with a partial pressure suit. This will always be a positive g load.

Vibration acceleration will occur at the onset of a high-speed stall. This may occur when the pilot is trying to track and turn inside of his maneuvering target. The airplane will not usually stall before entering longitudinal pitch up. Some buffet warning prior to pitch-up will be present in subsonic flight. There also may be some lateral oscillation prior to the stall. The buffet frequency is about 2 to 3 Hz. At this frequency the human body responds to vibration as a rigid body. Therefore, the IHMS/D will see the vibration input at the seat of 2 to 3 Hz. Studies by Teare and Parks indicate maximum reading errors at the vibration range 10-25 Hz. The reading material used moved at the same frequency as the subject. Guiguard and Irving conducted studies that indicate maximum visual degradation at 3.4 Hz. The reading material used in these studies was stationary.

11) Temperature and pressure

Temperature and pressure are hazards to the crewman only if he ejects at high altitude and loses his helmet. Pressure is a hazard only if cabin pressurization is lost. However, the IHMS/D will not cause loss of cabin pressure. The operational range of temperature inside the canopy on the ground to ejection at altitude is +160°F to -67°F. The operational range of pressure may be 29.92. inch Hg. to 3.44 inch Hg.

12) High ambient light

Natural levels of illumination do not present a hazard to the crewman. However, of all man's sensory facilities, his eyes are the most important for flying. The brilliant flash of light which is a hazard is the light incident to a nuclear detonation. This problem is beyond the scope of the IHMS/D design. For high-altitude flight, sun glasses or visors are worn to provide protection against ultraviolet radiation and high light intensities.

In high-ambient, high-altitude light the instruments and other shaded areas of the cockpit become darker, while the sunlit areas are very glaring. The reading of instruments becomes difficult. The problem can be solved by increasing instrument lighting intensity or by a variable density visor or both.

13) Toxic substances

This subject is discussed under chemical hazards.

14) Physical strain

The primary physical strain will be the fatigue generated in the crewman by wearing the IHMS/D. Fatigue is very difficult to evaluate analytically. The study results reported in Reference 2 indicate 24 percent of USAF helmet-wearing population thought the present HGU-2A/P helmet too heavy. "In addition to reducing the weight of the helmet and its associated equipment, it is desirable to consider the weight of helmets in terms of pressure distribution over the crewmember's head." For the "average" head, the helmet weight is 0.0975 pounds/in^2 of projected head area.

15) Radiation

The primary radiation hazards are X-rays from the CRT. The CRT is well shielded by its attachment fixture, by the helmet shell and by the

shielding built into the tube. X-ray radiation should not be a hazard for the IHMS/D. Only a test, designed to measure X-rays, can quantify this potential hazard.

16) Wind blast

This hazard occurs during the initial phase of escape via an ejection seat. The ejection seat is designed to operate at 600 knots at sea level. The dynamic pressure at this operation boundary is approximately 1200 pounds/ ft^2. The onset of this pressure should occur 10 ms after canopy separation. The seat remains attached to the aircraft for an additional 10 ms. Approximately 1000 ms after seat/aircraft separation the dynamic pressure is approximately 250 pounds/ft^2. At this time the man/seat velocity has decreased to 300 knots, for the advanced concept escape system.

17) Impact

The work of Dr. Guardjian and Dr. Snively have defined the tolerance level beyond which potential fatal head injury occurs. The human tolerance limit curve has been constructed using initial velocity and parametric ideal stopping distances, Figure 23. The equation used in the calculation was $-a = 2(s-vit)/(t)^2$, where:

a = acceleration	vi = initial velocity
s = distance	t = time, pulse duration

For Model 7A and Model 8 the liner is designed to be one inch thick over the forehead. From Figure 23, it is apparent that head impacts at initial velocities greater than 240 inches/second (20 feet/second) are in the potential fatal region. Impact can occur on a hard landing or during ejection or in post ejection phases.

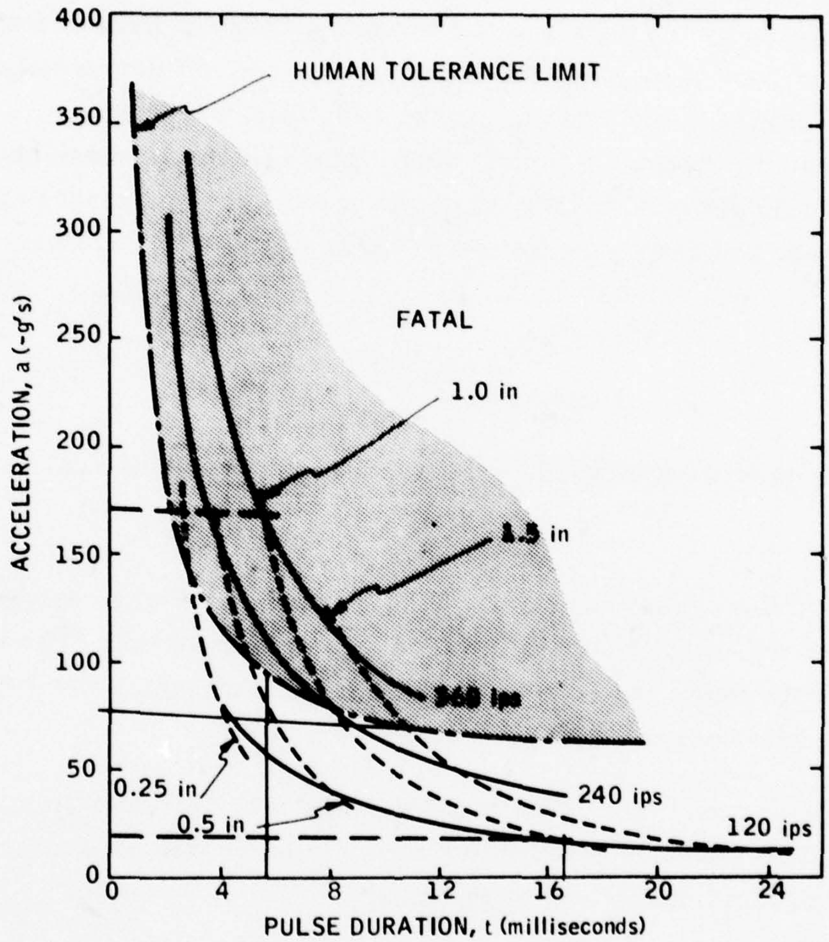

Figure 23. Human Head Impact Tolerance Limits

18) Ballistics

This potential hazard is related to ejection and wind blast. This hazard is generated by the debris in the cockpit hitting the helmet and/or visor while the seat is attached to aircraft. The cockpit debris becomes a hazard only if in the form of chunks resulting, for example, when the aircraft structure disintegrates. The velocity of these chunks can only be estimated. We recommend that the wind blast criteria supersede and satisfy ballistics criteria.

Results

The following general statements are based upon this mechanical hazards analysis:

1) The visor must remain in place on the helmet when subjected to a dynamic airload of 1200 pounds/ft^2 for 10 ms. The visor must remain in place for an additional 1000 ms as the dynamic airload decreases to 250 pounds/ft^2.

2) If a crewman stumbles while wearing the IHMS/D helmet, 100 foot-pounds of work are done by the helmet assembly in absorbing the energy of this fall.

3) The IHMS/D will be subjected to positive acceleration of 20 g at rates of onset up to 250 g/second during ejection.

4) The normal operational g load on the IHMS/D assembly will be 9g, positive direction.

Electric Shock Tolerance

The purpose of this study was to document and recommend an electric shock tolerance envelope for the operator, the user of the HMS/D. It is a small current applied over a short period of time that kills. For the general environment of the cockpit, the electric shock human response envelope can be described as shown in Figure 24.

The time duration of the shock exposure is also a very important factor in the fatality of a shock. Dalziel and Lee have developed a formula from their research data to define the allowable 60 Hz current time duration shock for

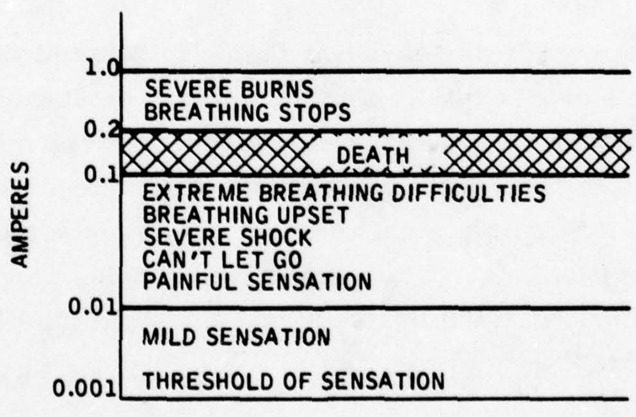

Figure 24. Electric Shock Response

the average adult male which will not produce fibrillation of the heart:

$$I = 116/T^{-0.5} \text{ ma (rms)}$$

where

I = Allowable current in milliamperes flowing through the subject arm to arm

T = Seconds time application of the electric shock (data base from 8 ms to 5 seconds)

The Honeywell experts on medical electronics recommend the allowable direct current which will not produce heart fibrillation as: $I = 58/T^{-0.5}$ ma (rms). Our experts feel we can use these formulas for shock durations of less than 8 milliseconds duration.

The post shock treatment is an important factor in determining whether or not a given electric shock is fatal. For the general environmental conditions of the cockpit, 0.10 to 0.20 ampere of current through the body will cause death if prompt (within three minutes) post shock treatment is not administered to the victim. It is impossible for a rescuer coming upon the accident victim to recognize the fibrillation condition in the victim unless there are the obvious broken wires in contact with the body. It takes a large jolt of energy to defibrillate the heart.

Discussion --

1. Fibrillation -- What Is It? -- It is the random uncontrolled contraction of the heart muscles. Normally, contraction of muscle cells in the heart are controlled by a pacemaker, the sincatrial (SA) node. Below it is another clump of specialized cells, the atrioventricular (AV) node. Other specialized

cells, called Purkinje fibers, branch out from the AV node through the ventricular walls. The pumping cycle (of the heart) starts when the SA node contracts, sending out electrical signals some of which reach the AV node, then go through the Purkinje fibers, completing the cycle.

There is mutiny, however, if an external current passes through a section of the heart; cells there may contract without waiting for commands from the pacemaker and when they contract they send out signals just like those of the pacemaker; so the mutiny can spread. When muscle cells are contracting randomly and too rapidly, the heart is said to be fibrillating.

Removing the current won't restore order; once a heart starts fibrillating, it takes a large jolt of energy to resynchronize, or defibrillate it.

2. Lethal Electric Current -- Man is very sensitive to electric currents. Researchers at UCLA, Berkeley, conducted tests with volunteers (134 men and 28 women). Of these 25 were between 26 and 46 years old, and the remainder were between 21 to 25 years old. This study was to determine "let-go current." The smallest electric shock of importance is that current which causes loss of voluntary control of the hand when an electrified object is grasped. The report developed 16 ma for men and 10.5 ma for women as the maximum let-go current. Ventricular fibrillation is considered the most dangerous electric shock hazard. Minimum current to produce heart fibrillation is proportional to body weight, (Reference 10).

Gross shock occurs when the current passes through the skin. Skin resistance can run as high as one megohm, depending on cleanliness and dryness of the skin. Under clean medical conditions, resistance of the skin is around 1000 ohms. A current of around 20 ma flowing through this resistance can cause fibrillation.

Gross shock can be lethal in two ways. Current through the skull may attack the brain's respiratory control center. Current entering elsewhere can paralyze the muscles used in breathing.

(Leakage currents are a major concern of medical instrumentation designers and they may be our concern also.)

Post Shock Treatment -- Cut voltage and/or remove victim from contact as quickly as possible, but without endangering your own safety. Use a length of dry wood, rope, blanket, etc., to pry or pull the victim loose. Don't waste valuable time looking for the power switch. The resistance of the victim's contact decreases with time. The fatal 100 to 200 ma level may be reached if action is delayed.

If the victim is unconscious and has stopped breathing, start artificial respiration at once. Do not stop resuscitation until medical authority pronounces the victim beyond help. It may take as long as eight hours to revive the patient. There may be no pulse and condition similar to rigor mortis may be present; however, these are the manifestations of shock and are not an indication the victim has succumbed.

Victims of high-voltage shock usually respond to artificial respiration more readily than the victims of low-voltage shock. The reason may be the merciful clamping of the heart, owing to the high-current densities associated with high voltages. However, lest these details be misinterpreted, the only reasonable conclusion that can be drawn is that 75 volts are just as lethal as 750 volts.

The actual resistance of the body varies depending on the points of contact and the skin condition (moist and dry). Between the ears, for example, the internal resistance (less than skin resistance) is only 100 ohms, while from hand to foot it is closer to 500 ohms. The skin resistance may vary from 100 ohms for wet skin to over 500,000 ohms for dry skin.

Conclusion -- The resistance through the human head is very low (100 ohms). The HMS/D helmet attaches a high-voltage load to the pilot's head. It is absolutely vital that any direct application of the HMD voltage or any significant amount of leakage current across HMD insulation be prevented from reaching the wearer's head. Carefully grounded shields on the CRT and its associated cabling are one valid approach to this protection. Severe current limits on HMD power supplies are another. The choice of protective technique should be made on the basis of the degree of protection offered rather than on any tradeoff of this parameter against other design considerations.

Helmet Function Inquiry

Four reports, supplied by Major Eliason, were reviewed and the data summarized. Reference 11 reviews the effect of the dual visor on helmet retention during ejection. For the data period, 1968 to 1969, there was no significant difference in retention between single and dual visor helmets. Injury frequency during ejection or injury severity could not be related to single or dual visors.

Reference 12 reviews the role of helmet loss in head injuries for the USAF for the 1963-1967 period. In these 838 ejections, there were the following results:

1) There were fatal or major injuries in 38 percent (318) of these ejections.

2) There were fatal head injuries in 3.2 percent (27) of these ejections.

3) The helmets were lost in 14.6 percent (122) of these ejections.

4) The helmets were lost in 36.4 percent of the fatalities -- head injury.

5) The helmets were retained in 7.3 percent of the fataltīes -- head injury.

6) The helmets were lost in 15 percent of major injuries -- head injury.

7) The helmets were retained in 6 percent of major injuries -- head injury.

Pilot activities and helmet loss incurred in each activity are as follows:

1) Before ejection, 5 percent of helmets lost.
2) During ejection, 69 percent of helmets lost.
3) During free fall, 23 percent of helmets lost.
4) During descent, no helmets lost.
5) During landing, 3 percent of helmets lost.

Aircraft speed was not a factor in these helmet losses. The stability of the seat seemed to be a factor which caused the loss. The history of helmet retention by aircraft type seats is:

- F-105 -- 77.2 percent of helmets retained
- F-100 -- 84.2 percent of helmets retained
- F-4 -- 91.9 percent of helmets retained

Reference 13 describes helmet protection in aircraft crashes for the 1963-1967 period. Body restraints seems to be the most important factor in preventing head injury in survivable crashes. During the data period there were the following results.

1) Of all crashes, 72.9 percent (951) were survivable.
2) Of all jet fighter crashes, 65.5 percent were survivable.
3) Of all helicopter crashes, 93.4 percent were survivable.
4) Of the fatalities, 2.7 percent were fatal head injuries.
5) Of the major injuries, 16 percent were head injuries.
6) Of all the injured, 0.5 percent were injured and were wearing seat belts only.
7) Of all the injured, 0.3 percent were injured and were wearing both seat belt and shoulder harness.

Reference 13 noted that not all the persons involved in these crashes had helmets available. Of those that had helmets available, 2.4 percent of the fatal and major injuries had their helmet on; 2.8 percent of the fatal and major injuries had their helmets off.

Reference 14 describes the role of helmet loss in USAF aircrew head injury during ejection. From 1963 through 1967, there were 838 ejections from USAF aircraft. In these, 122 individuals lost their helmets. There were 318 major or fatal injuries of which 27 involved the head. The head was implicated in 8.4 percent of all fatal or major injuries. Head injury accounted for 36.4 percent of all fatalities where the helmet was lost. Conversely, head injury accounted for 7.3 percent of fatalities where the helmet was retained. The analysis of the nine major head injuries where the helmet was retained revealed that seven were facial fractures, burns and lacerations which could have been prevented if the visor had been properly used.

A series of preliminary experiments were performed on the NADC Human Centrifuge to determine the effect of steady-state + G_z accelerations on a subject's ability to aim a helmet-mounted sight at stationary targets located at four extreme positions in the subject's field of view (Ref. 15). Performance was measured as time on target measured by a photo cell. The subject was on target when his line of sight was within 1/4 degree of target center. The targets were located at ±45 degrees and zero degrees azimuth and zero and +32 degrees elevation. The test trial peak G duration was 20 sec. Figure 25 describes time on target versus g load. It indicates the average performance and the best individual performance versus target elevation for targets at ±45 degrees azimuth. Figure 26 describes time on target versus target azimuth location. The curves are drawn for the average performance for six subjects. The range of performance by subject for a given condition versus the average performance for that condition was greater than the range between averages of the performance for all the conditions.

The results of the study, Reference 15, describe the pilot's tracking performance in the pitch plane with 16 ounces added to the helmet. It is assumed that the weight added was balanced through the helmet cg. The data indicate that in the forward hemisphere for time on target, target elevation is more important than target azimuth location.

References 16 and 17 describe the experiments to measure helmet movement in the lateral plane versus g loads. The experiments were conducted to gain an understanding of head and helmet dynamics under the influences of $+G_z$ forces. Two different helmets were used: the standard HGU-2A/P and the Gentex type DH129-2, equipped with an adjustable web suspension. The helmets weighed from 1240 to 1430 grams (43.5 to 50.5 ounces). The maximum weight added was 40 ounces with a maximum eccentric load of 15 ounces. The center of mass of each weight was maintained at one inch from the helmet shell.

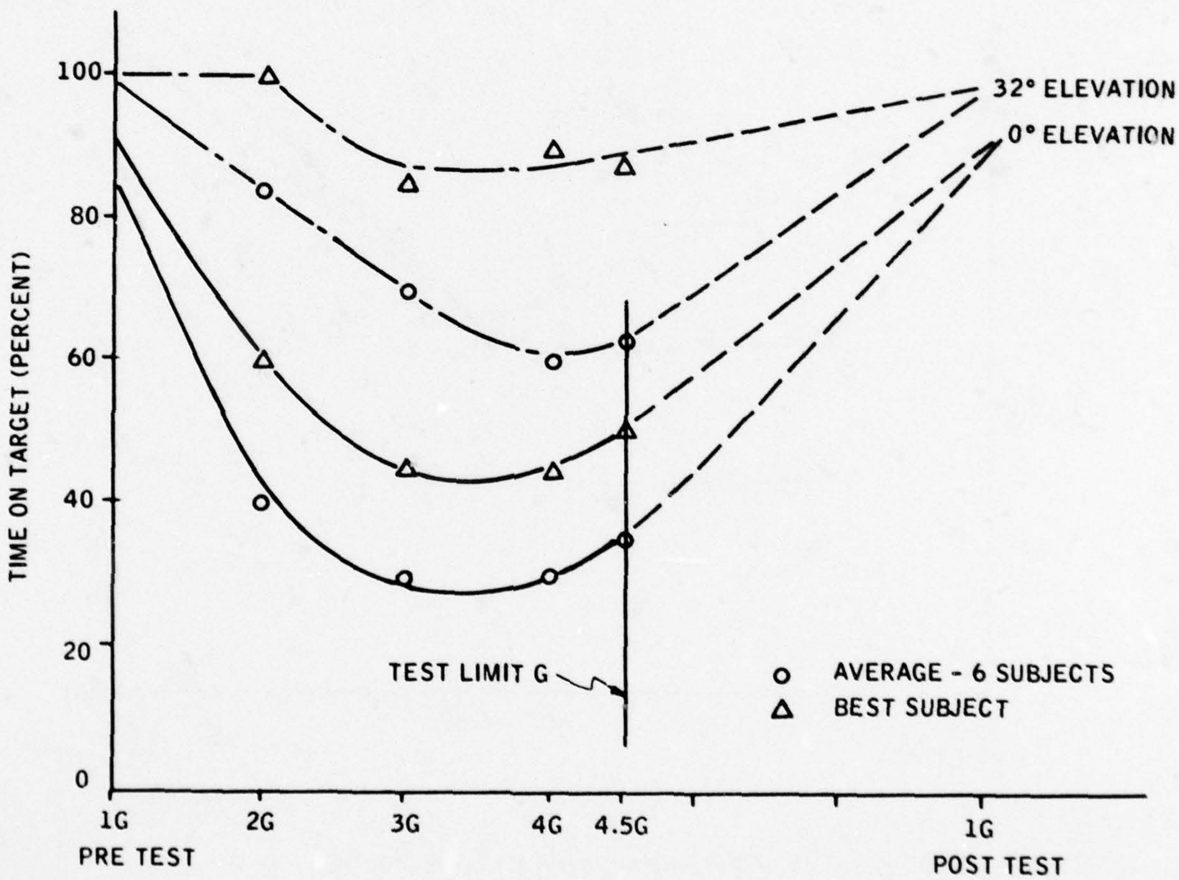

Figure 25. Time on Target versus G Load versus Elevation Target at ±45° Azimuth

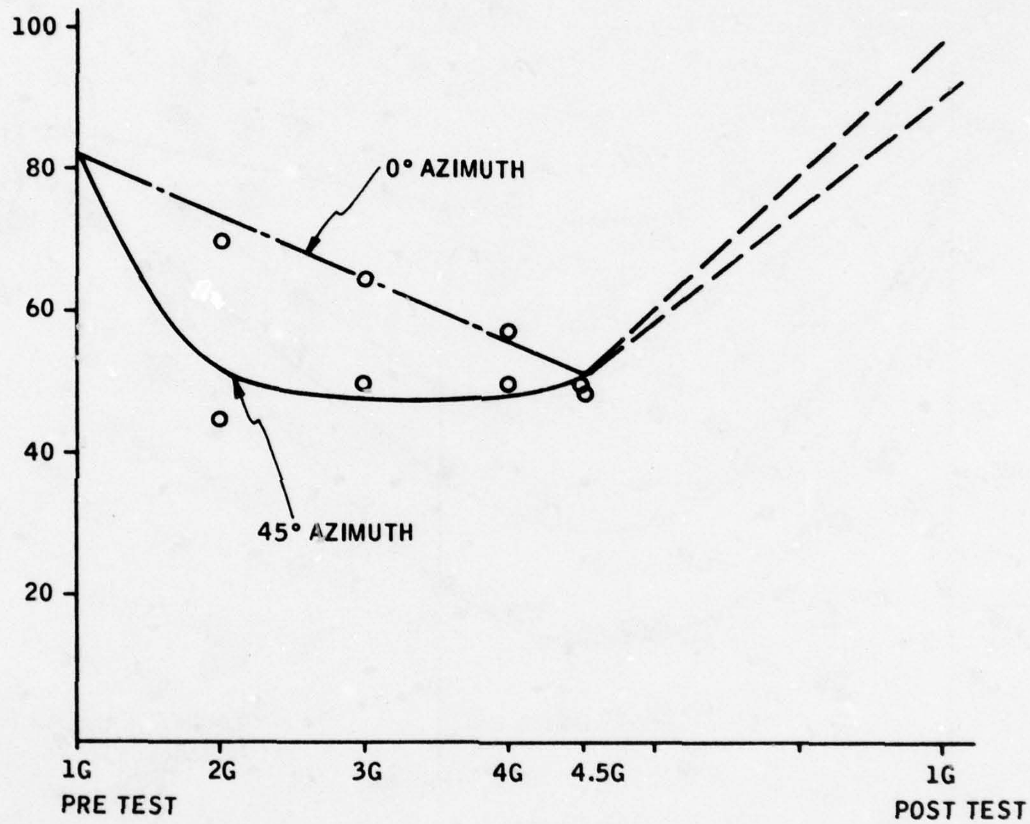

Figure 26. Time on Target versus G Load versus Azimuth Target at 32° Elevation

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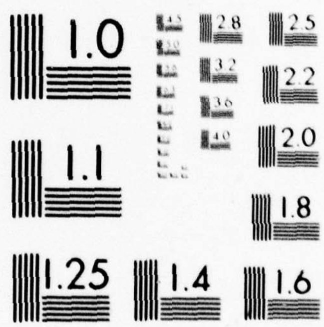

1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

Significant results of this experiment are:

1) The helmet does not return to its neutral position after unloading from a high g run (set ranged from 1 to 11mm as measured at the reticle).

2) There was no difference between helmets as measured by reticle displacement.

3) Displacement was proportional to g load:

- 3 to 12mm at 2G
- 8 to 24mm at 6G

4) There was little relationship between helmet load, or load distribution and reticle displacements.

Figures 27 and 28 describe the location of the center of gravity of the Air Force helmets without liners. The method used to determine the cg was to suspend the helmet through tooling holes and then mark the vertical through that suspension point. The intersection of three of these vertical lines designated the cg.

Impact protection is the single most important function of the helmets currently in use by our aircrew, Reference 18. Aircrew protective equipment must meet three general requirements:

1) User acceptance -- will the crewman wear/use it?

2) Function -- will it protect against the threat?

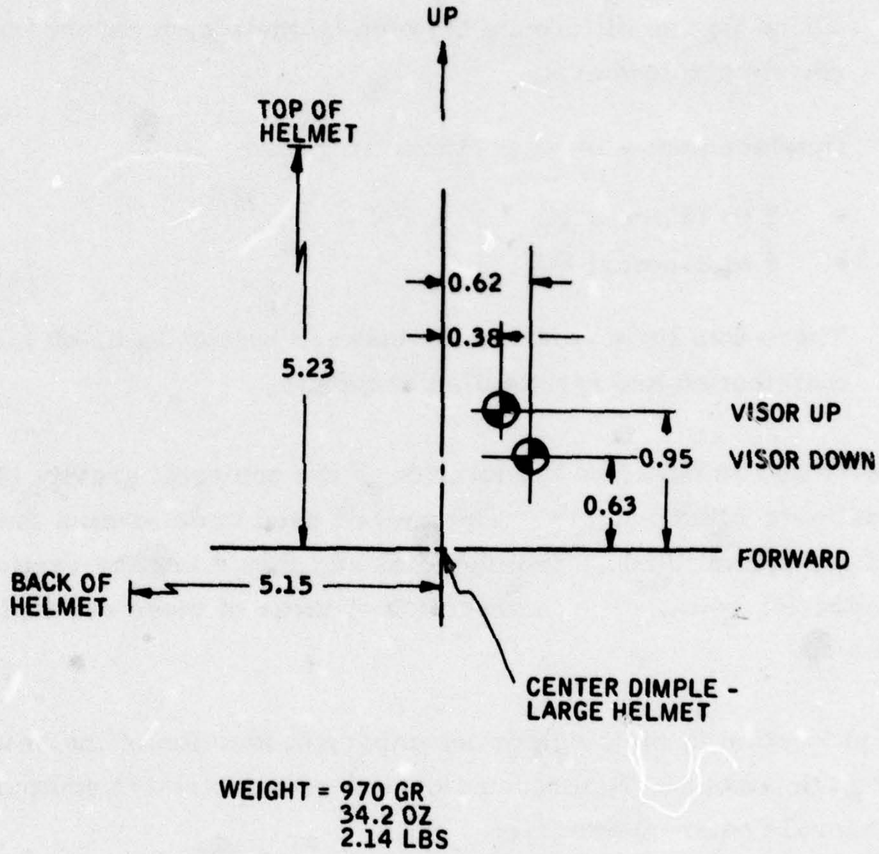
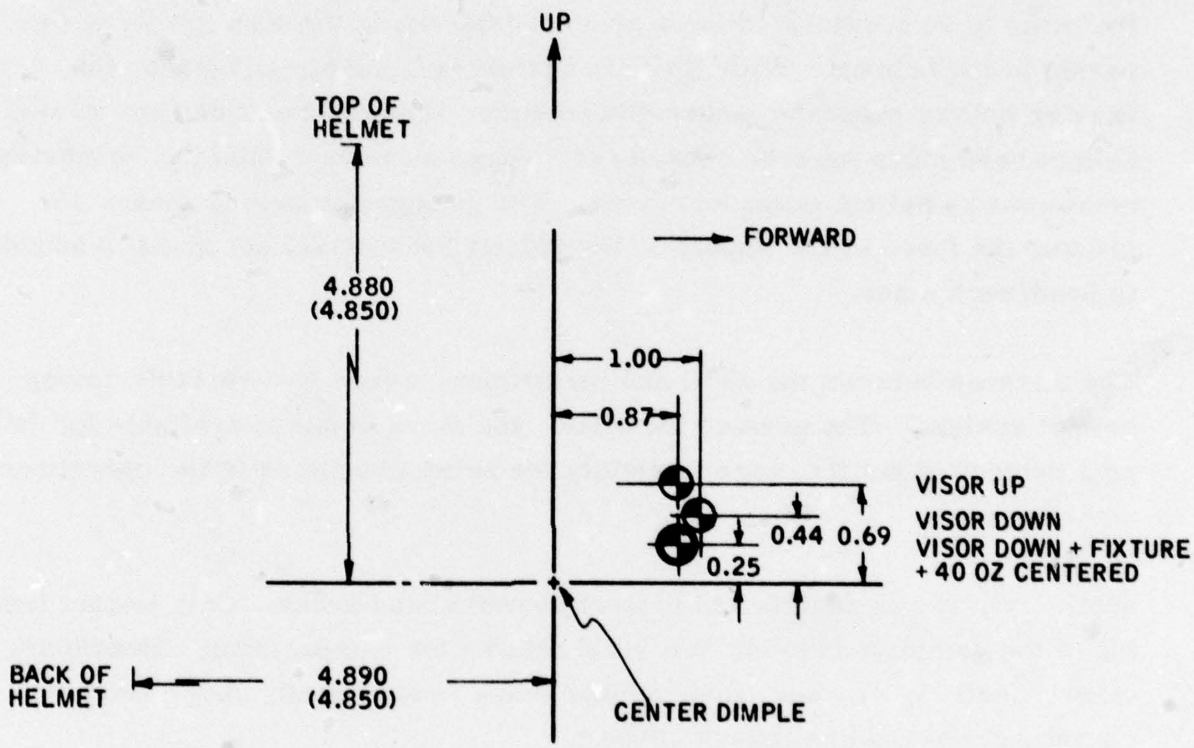


Figure 27. Helmet Center of Gravity -- Large Size



	BASIC	WITH FIXTURE	EXTRA WEIGHTS
WEIGHT:	899 GRS	1235 GRS	20.4
	31.8 OZ	43.5 OZ	30.4
	1.98 LBS	2.7 LBS	40.6

Figure 28. Helmet Center of Gravity -- Medium Size

3) Functional noninterference -- Does it interfere with normal and necessary cockpit functions, crew tasks?

The helmet variables are mass, offset, shell design and the liner. Helmet mass acts "protectively" as it is increased, because F = ma. The greater the mass to be accelerated for a given acceleration, the less the force imparted to the helmet. With impacts against deformable structure, the heavier helmet may take larger deformation. The deformation limit of the helmet head mass must be considered. Given an impact velocity, protection decreases as helmet mass increases. The greater the helmet mass, the greater the force of the impact on the helmet because helmet mass is added to head/neck mass.

The distance between the shell and the helmet surface is a variable among helmet designs. The greater the offset, the more distance available for impact protection but the more unwieldly the helmet becomes in the operational environment.

Shell curvature is designed to protect specific head areas. Only impact testing of the complete helmets will yield results for comparisons. Headform, offset, shell rigidity and other variables are interrelated. Any change in curvature will require impact testing.

Liner materials are important for acceleration attenuation of the head/neck/helmet assemble on impact. The parameters of liner design are density, thickness, resiliency and adhesion to the helmet shell. The general helmet tests measure these qualities in their net effect on head impact acceleration attenuation. The overall seat restraint system also affects the helmet's protection requirements and capabilities.

Conclusions

General conclusions from this study are:

1) Helmet retention during ejection is important for the crewman's survival. (The program has not scheduled any testing to measure the effects of our IHMS/D design upon helmet retention.)

2) The helmet takes some "permanent set" due to g loads. (Vernier adjustments for the display image are required for the operational environment.)

3) The helmet center of gravity envelope range is ±0.4 inch for 40 inch-ounces.

4) The head/neck/helmet center of gravity envelope range is ±0.15 inch for 40 inch-ounces.

5) A maximum delta weight for IHMS/D cannot be specified on the basis of the data available in this study.

Brow Protection Shield

The optical chain of the Mark I, Mod I helmet, in order to maintain a low profile in the completed helmet, required the helmet shell to be notched as shown in Figure 29. This allowed the proper spacing between the collimation optics and the visor without requiring undue protrusion. The notch, on review, was considered to weaken the helmet shell sufficiently to require reinforcement. The end of the collimation optics as it extended inside of the helmet and close to the operator's forehead appeared to offer a danger to the wearer in case of impact in the area of the optics assembly.

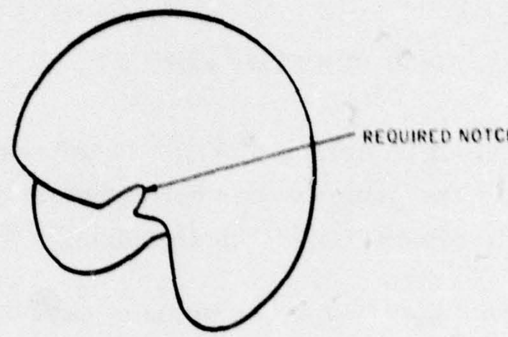


Figure 29. Notched Helmet Shell

A number of alternate solutions to these problems were considered. The objectives of the study were to restore the structural integrity of the helmet, spread the concentrated impact load from the collimation optics over a large smooth area, and to protect the operator's eye from damage in case the helmet were to rotate downward onto the face. Several alternatives were considered, including the following:

1) Add a padded plate under the boresight mirror to protect the forehead and eyeball. Extend the contour of the liner 1/2 inch with a small 1/16 inch fiberglass cloth layup backed by foam padding. Extend the leather liner to cover this assembly. This fix would be added to each pilot's helmet liner.

2) Add a formed fiberglass plate to bridge the notch and contour it to protect against the boresight mirror by distributing the load. Bond this formed cup to the helmet. Fill the void with foam material. Each pilot's helmet liner would be cut out to fit helmet modification.

3) Bridge the notch with a flat fiberglass patch. Blend the edges into the helmet contour. Add a plate to the liner as in Solution 1 to protect against the boresight mirror.

4) Sculpture the liner as required to fit the collimator assembly. Form the liner leather cover to extend under the boresight mirror to protect the forehead.

These alternate solutions were reviewed and coordinated with AMRL. Solution 3 was developed as the best answer to the problems of structural integrity and pilot protection. Figure 30 shows the arrangement of the added components and Figure 31 shows the appearance of the helmet with the brow protector in place.

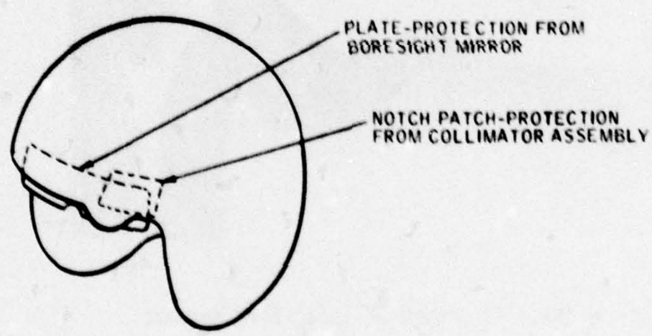


Figure 30. Protective Elements

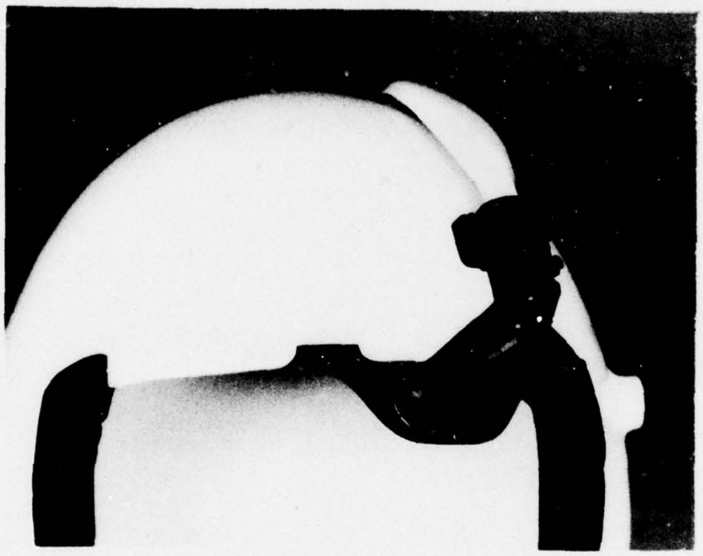


Figure 31. Current Brow Protector

SECTION IV
MONITORING AND TRAINING REQUIREMENTS

INTRODUCTION

The term monitoring means to watch, observe, or check on performance, to review and sometimes to control the actions of an operator. General categories of operations the USAF may want to monitor to varying degrees include:

- Combat flight operations - (air-to-air; air-to-ground; ground-to-air; ICBM launch and re-entry)
- Noncombat flight operations
- Reconnaissance
- Base security
- Training
- Command post operations
- Space operations
- Maintenance operations

Why monitor various aspects of the operations listed above? Simply to observe or check on results or outcomes of the various activities involved and to learn from them. Monitoring is applicable to:

- Observation of techniques or practices (as in training operations)
- Damage assessment and accuracy check of weapons delivery
- Target identification and categorization

- Perimeter surveillance of military reservations
- Command post activities (ground-based as well as airborne) which check progress of planned operations

While visually coupled systems may be used for all of these applications, monitoring of VCS operation is most likely to be used in the first two. In traditional control tasks, such as flying a link trainer or in firing of guns or rockets, it has been possible to use strip chart recordings or still or motion picture photography to measure operator performance. As the control task is taken over by a VCS, it becomes more and more necessary for the monitoring equipment to "see" the same scene which is actually perceived by the operator. This discussion therefore will be directed toward the monitoring of a number of typical applications in the VCS area. The discussion presented here is to serve as a starting point for system concept definition and the generation of requirements and specifications for equipment needed to implement the concepts developed.

EXISTING VCS MONITORING SYSTEMS

Three broad categories of VCS may be identified. In the first of these, the operator controls some device such as a missile seeker, or an IR sensor, by means of his head motion, and the monitor's task is to determine both the operator's inputs to the system and the system's reaction to them. An example of this type of VCS is the Air Force SHAG System in which the operator's head motion and overall system performance are both recorded by a helmet mounted camera. In a second type of VCS, a display of information vital to the operator is presented in some fixed relationship to the aircraft. The operator is required to move his head into alignment with the display in order to see it and sees the display only when his head is properly aligned. In this case, it is not necessary to provide a flexibly mounted monitoring system, and the field of view of the monitor may be much more circumscribed

than in the first situation. An example of this type of monitoring is the unit being applied in flight testing the Hot Line Gun Sight. In the third situation, the operator performs no control function with his head motion. It is desirable, however, to monitor the scene at which he is looking. An example of this is to be found in the medical monitor which Honeywell has recently demonstrated to a number of Air Force personnel.

Line-of-Sight Monitor

Where the operator's line-of-sight direction is to be monitored, it is necessary to provide a sensor which will swivel as he moves his head. Figure 32 shows a helmet equipped to project a collimated reticle image by reflection from the inside surface of the helmet's visor. A helmet-mounted television camera with an optical system which makes its line of sight colinear with that of the operator serves as a system monitor. In the application for which this helmet was prepared, it was necessary to monitor not only the direction in which the controlled device was pointed, but also the exact scene which was perceived by the operator. Since the operator's vision was at least partially obscured by the structure of the aircraft cockpit, the only way in which his exact vision could be reproduced was by providing a sensor which was colinear with his vision regardless of head angle or head translation. Figure 33 is an optical schematic of the camera system used.

The head-mounted camera monitor for a varying line of sight offers the advantages of instantaneous response and near perfect alignment of the monitoring device to the parameter being monitored. It is easy to implement and requires no servo connection between the head and the monitoring device. It has two disadvantages which are not insignificant in the fighter concept. It adds weight and unbalanced weight to the helmet, and it places a beamsplitter in the pilot's line of sight. In some circumstances, the addition of the computer may cause some degradation in his normal vision. The helmet-mounted camera shown

Figure 32. VCS Helmet with Head-Mounted TV Camera

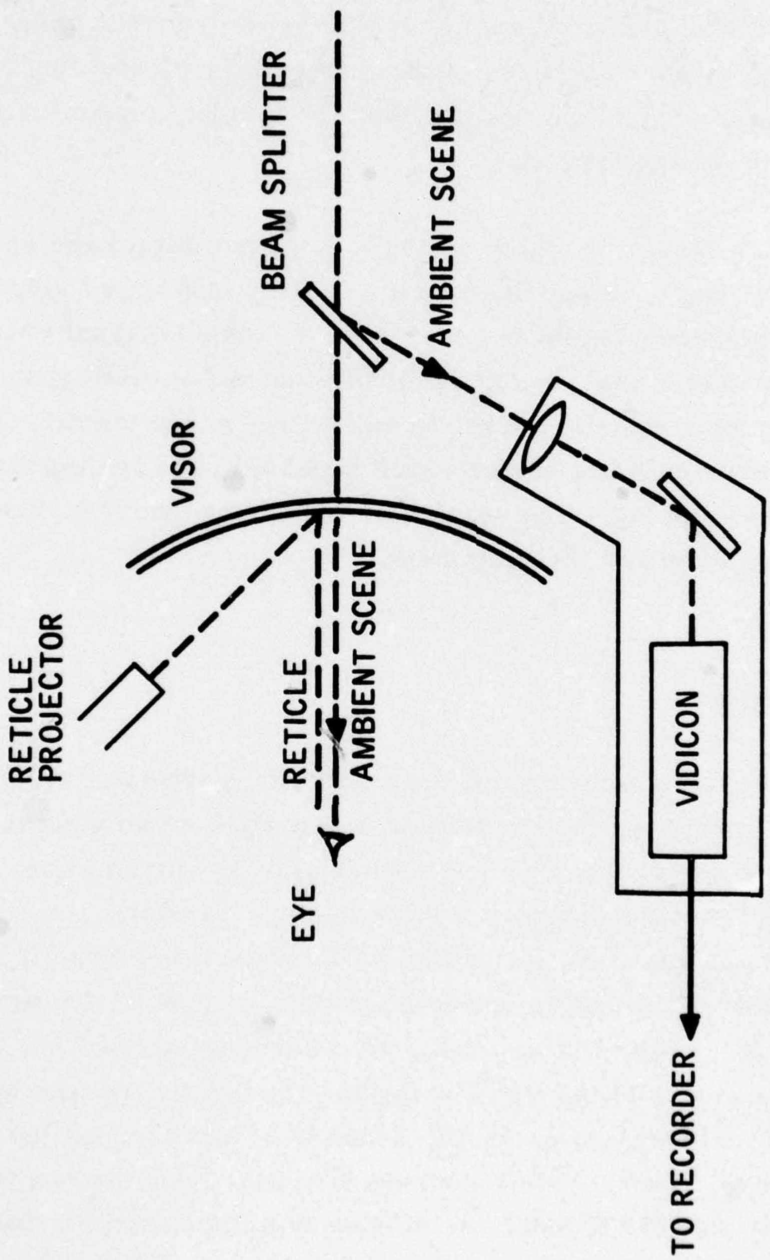


Figure 33. Head-Mounted Camera

in Figure 32 has approximately the same weight as a HMD, and where no display is required the weight of the camera may be acceptable. In VCS arrangements which also require the use of a HMD, the combined weight of camera, display, and head position sensing equipment may be too great for use in a fighter environment. For this reason, every effort should be made to use some remotely located sensor rather than the helmet-mounted camera for this particular type of application.

Figure 34 shows a VCS system in which a monitor of the pilot's head position and, therefore, line of sight, is provided by a remotely controlled gimbaled sensor which tracks his line of sight but does not add any additional weight or unbalance to his helmet. The sensor need not be added specifically for this purpose, but may be a missile seeker head, a long-range identification device, a FLIR, or other existing device which is suited to providing the information required for monitoring. The particular sensor chosen will depend upon the aircraft being used and its equipment.

Fixed Direction Monitor

Where the phenomenon to be monitored occurs only in a particular sight line with respect to the aircraft, as for example in a gun sight or an instrument landing display, it is not necessary to take the angular or translational motion of the pilot's head into account in preparing the monitor imagery. It may be desirable to translate the imagery in the display in response to head motion, but only for the purpose of indicating whether the pilot is able to see the display or not. Where the imagery is displayed on a heads up display (HUD) fastened firmly to the aircraft, the monitoring task is relatively simple, since it requires only a means of providing a forward view through the imagery on the display. When a helmet-mounted display replaces the HUD, the task of monitoring directly through the display is complicated by the problems of weight and unbalance described previously. In a flight test

program, now underway at Tyndall Air Force Base, the device shown schematically in Figure 35 is being used for monitoring purposes. The monitoring device is made up of a CRT and two beamsplitters arranged in line before the CRT. The lower beamsplitter is used to feed a combination of the CRT imagery and the ambient scene to the monitoring camera. A portion of the energy from the CRT passes through the lower beamsplitter and is reflected from the upper beamsplitter to the operator's eye. The upper beamsplitter also allows a certain amount of the ambient scene to pass through to operator as well. The monitor camera sees the same imagery seen by the operator viewing the target through the upper beamsplitter. The CRT in the monitoring device is driven in parallel with the CRT located in the helmet display. The upper beamsplitter of the monitoring device is used as a zero reference or boresight mark for the helmet sight/helmet display combination. Thus, during setup and calibration the helmet sight angles are compared against the direction set by the boresight pattern on the monitor device and any errors are zeroed out. Once that is done the pilot uses the helmet display rather than the boresight mark as a means of attacking the target. The head position as measured by the helmet sight system is used to position the display on the CRT in the helmet display. The imagery is translated on the face of the CRT in response to head motion in such a manner as to make the display appear to be stabilized in space parallel to the armament datum line of the aircraft. If the pilot turns his head farther than the angular field of view of the display, the imagery disappears from his vision.

The monitoring device shown in Figure 35 has the advantage of simplicity of design and a firm mount and positive alignment to the aircraft. Its disadvantage is that it is limited in its operation to a single line of sight with respect to the aircraft. It is also subject to the same type of misalignment errors which affect the variable line-of-sight monitor implemented with a gimbaled sensor system.

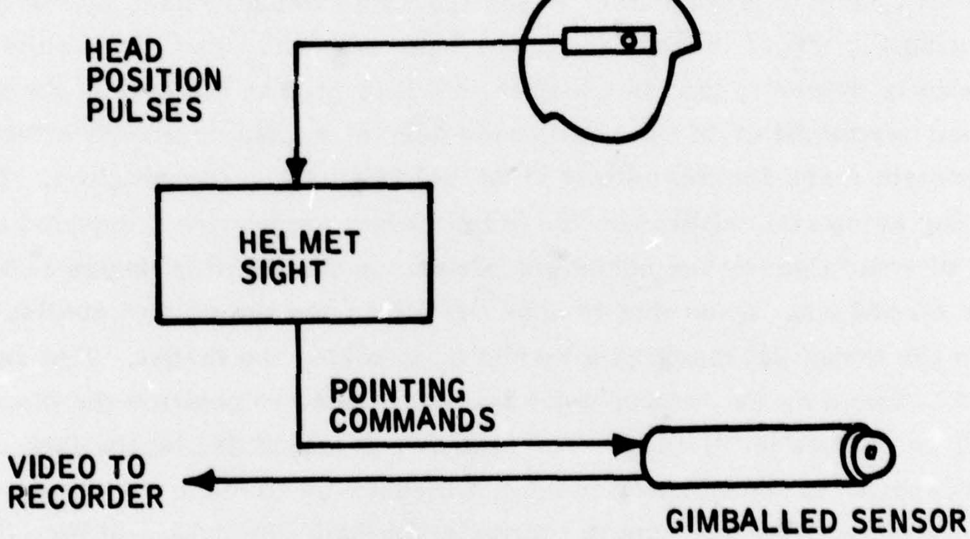


Figure 34. Remote Sensor Monitor

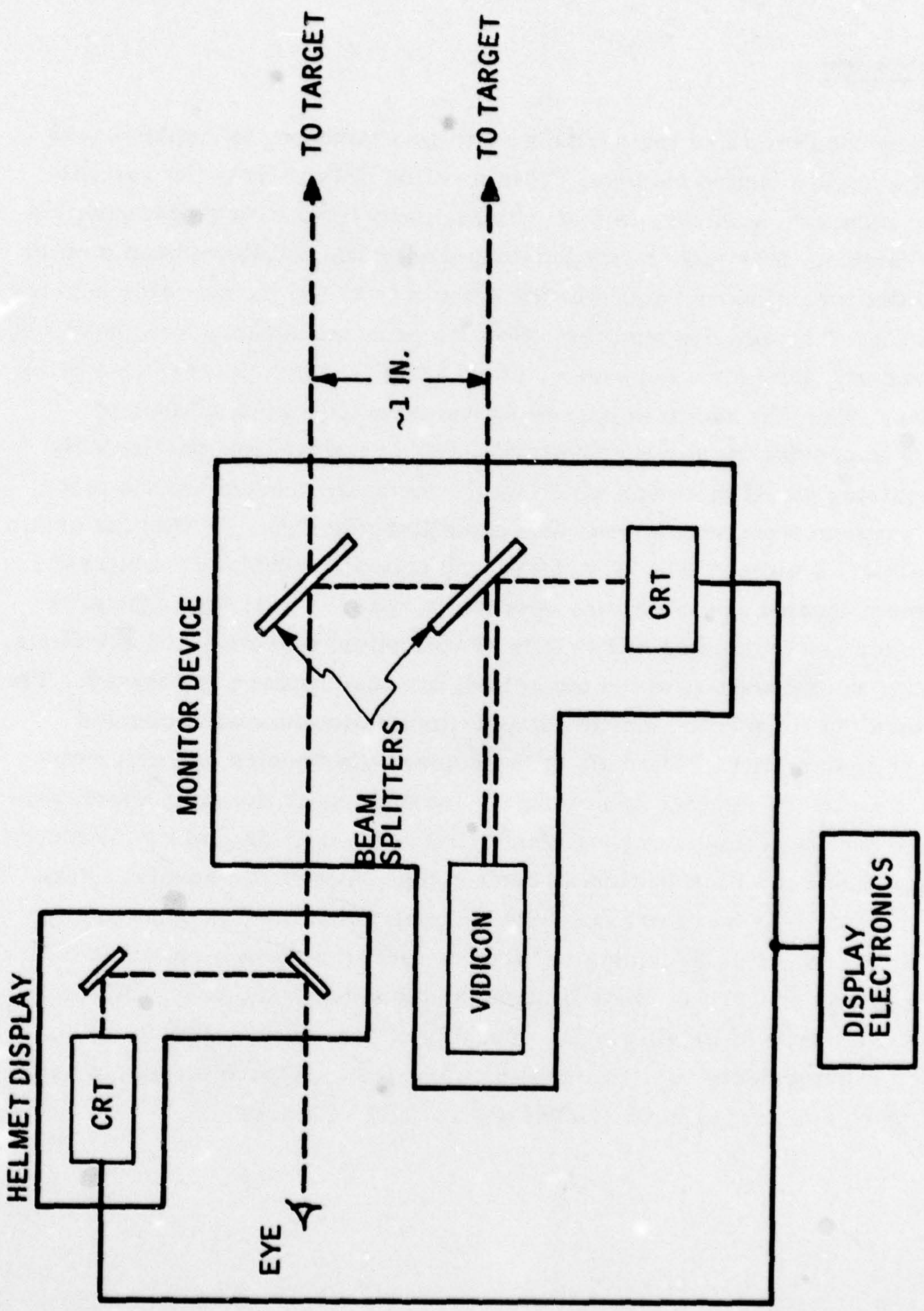


Figure 35. Fixed Sight Line Monitor

Activity Monitor

The activity monitor, like the variable sight line monitor, is implemented by use of a head-mounted camera. This monitor differs from the variable sight line monitor, however, in that it is not associated with a head position control function. It is rather an open-loop device which follows head motion and provides a continuous record of the objects to which the operator devotes his attention. The activity monitor offers its greatest advantage to those who wish to record, for future reference, some activity which is otherwise difficult to see. The unit shown in Figure 36 has been used on a number of occasions to provide video recordings of surgical operations, particularly those requiring small incisions which would normally prevent anyone other than the surgeon from seeing what was actually being done. Within the crown of the helmet, a vidicon tube is mounted and optically coupled to a mirror arrangement located just above the operator's nose. Twin, high-intensity light sources are located on either side of the optical objective and are focused to converge on the area at which the helmet mounted camera is focused. The system thus provides both monitoring and illumination functions coupled directly to head motion. The bulk of the camera electronics and drive circuitry and a picture monitor are remotely located, as is the lamp which provides light for the illuminators. Camera drive is fed to the helmet by means of a single cable and illumination by two flexible, fiber optic bundles. The activity monitor may be used to provide training materials, in this case for student surgeons, or to provide a permanent record of activities which either because of their danger, or their limiting environment, are very difficult to observe. This type of monitoring is probably of less direct application to Air Force requirements in flight than the other two. It is, however, a valid application of monitoring in the visual control and VCS area.

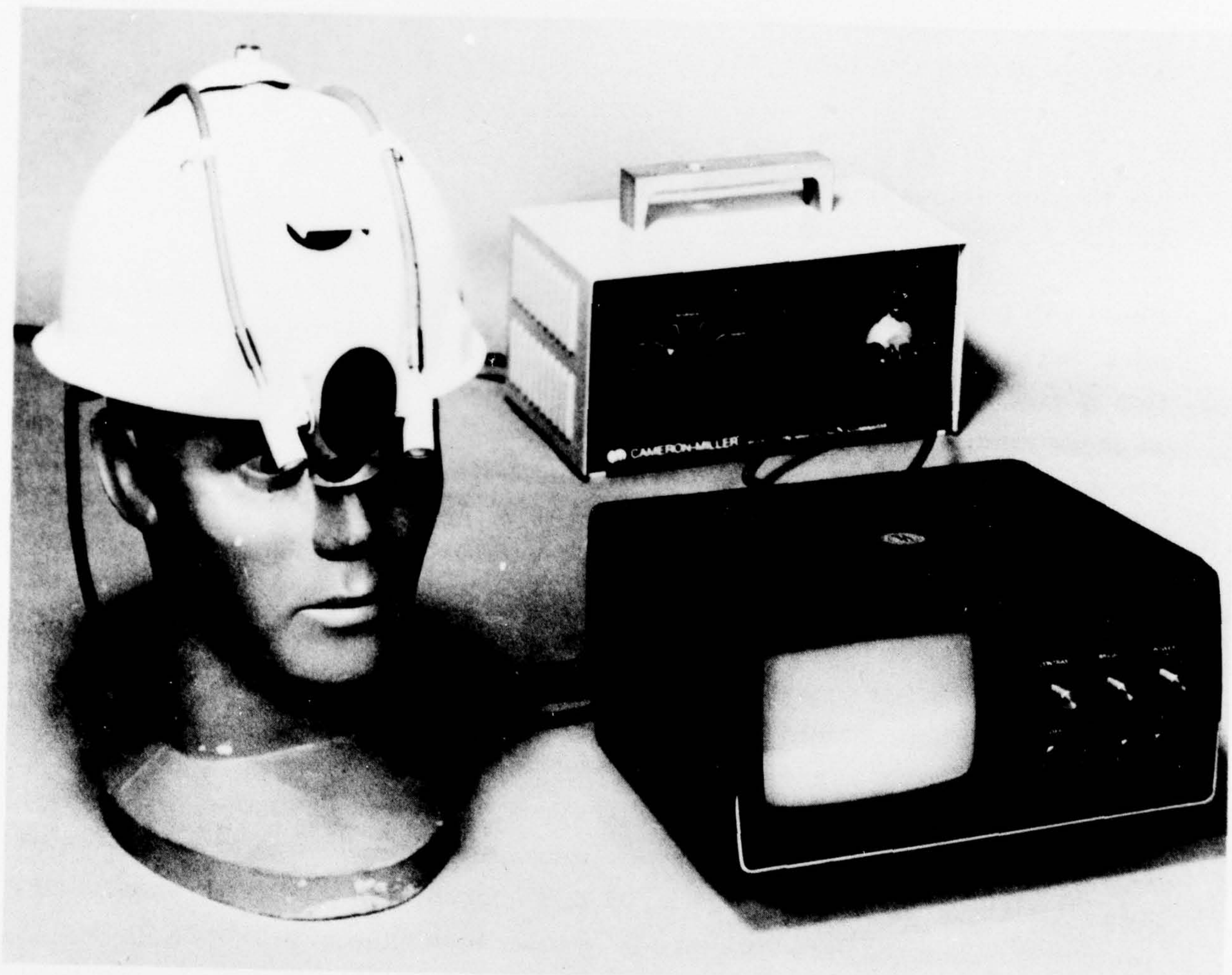


Figure 36. Medical Monitor Prototype

APPLICATIONS

The following paragraphs contain descriptions of a number of applications for monitoring. Air Force training operations, combat flight, and noncombat flight operations are discussed.

Air Combat Evaluator (ACE) - A Pilot Training System

Honeywell recently completed a study showing the feasibility of an ACE as an advanced gunsight evaluator and a pilot training aid. It is an airborne simulation of gunfire in the near-real environment of air combat maneuvering. Two or more aircraft actually engage in dogfights but fire only electronic bullets at each other. The simulator computes the bullet stream, determines its position relative to the target, calculates miss distances between bullets and target, and finally solves for the probable number of hits. The results from a simulated firing pass are displayed in real time on the gunsight as the number of hits computed. Results are monitored by a gunsight camera. Its film records the moment the trigger is depressed, and the number of hits scored as well as the approach to the target during the firing pass.

A more complete monitor of simulator operation seems desirable. Real-time assessment of trainee progress by an instructor is preferable to the student's own evaluation based on the number of hits scored. An instructor monitoring the student's approach tactics through a television system providing instant communication is far more effective than a review of gunsight film three days after the simulator runs.

Real-time monitoring can be provided by replacing the gunsight camera with a TV camera and transmitting its video output to a ground receiver for display at an instructor's station. Alternatively, where complete real-time monitoring is unnecessary, the video data can be recorded on tape and be ready for replay as soon as the training flight is over.

Another feature of the proposed ACE concept is a display of the electronic bullet stream (hot line) formed as the electronics bullets are fired toward the target. The effect would be the same as observing tracers as they are fired. With the electronic tracer pattern displayed on the target scene, an instructor can monitor the trainee handling of his guns and thereby judge whether he is using his gunsight properly. All data observed can be recorded on video tape for replay and review with the trainee after the flight.

A video monitor for the ACE may be very similar to the fixed sight line monitor shown in Figure 35. This monitor records what the pilot sees through his HMD and will be required for future ACEs where not only the gunsight but also a target will be displayed. This version of ACE allows air combat to be practiced solo; no target aircraft is required. The need for real-time monitoring will increase since no target plane will be present to comment on the flight. The instructor will observe student activities as they occur as well as after the training flight is over, comment on them, and suggest corrective action before the next run.

Simulator Training of Flight Crews

The USAF has invested vast sums of money in simulators for training flight crew members. Both ground-based and airborne simulators are used by trainees in becoming proficient in their jobs before being assigned to operational units. The monitoring requirements in this area are dictated by the need for an instructor to observe and check on the performance of a greater number of students now than in the past. Ground-based simulators of flight have far greater capability today than yesterday, where the student pilot "flew" by observing only the flight instruments. Today's simulators display a make-believe outside world as a reference as well as the flight dynamics through instrumentation. Landing approaches can be practiced during the same session that the student flies a simulated dogfight.

Instructor pilots will probably have to be remotely located from the students and may wish to monitor two or more at a time. The monitor will provide the information required by the instructor to grade the student's progress. This may include a display of what the student sees through his "windscreen" together with critical flight parameters. The instructor will have at his station the capability to insert changes to the environment into the simulation (such as turbulence, wind gusts, etc.) and to judge the student's response to changes.

SAC navigators and radar officers are trained on simulators of the flight environment to which they will be exposed. Again, airborne as well as ground-based simulators, are used. Honeywell Marine Systems Division has a contract presently to provide the ground-based simulators at Mather Air Force Base, California. In the past an instructor has been needed with each student. With proper displays one instructor could monitor the activities of two or more students at a time.

Remote Piloted Vehicles (RPV)

The use of RPVs in recent years has expanded to include many more missions than originally intended. The requirements for monitoring the operations of RPVs range from sensors to see where the vehicle is going to those required to retrieve it aboard a launch/recovery craft. It is interesting to note that, in controlling an RPV, the operator is also the monitoring agent, and a semi-automatic machine rather than a human operator is being monitored.

Reconnaissance with drone vehicles has been carried out for a number of years. Air-to-ground weapon delivery by RPVs is fairly new, and remotely piloted air-to-air combat has been studied as a potential means of improving maneuvering capability during a dogfight. In all these operations, the "pilot", remotely located from the combat vehicle, needs "eyes" aboard the vehicle to transmit the imagery necessary to allow him to make decisions regarding his next control input. The RPV's eyes will be TV and/or FLIR systems.

For air-to-ground weapon delivery, presently planned systems call for automatically controlled, preprogrammed approach paths to targets. Weapons are released at predetermined geographic coordinates, so these systems require extremely accurate navigation systems. Future RPV systems will probably feature fire control systems which search for and track a target once the vehicle has been brought into the target area by its navigation system. The release-on-coordinates approach will become a backup. If the remotely located pilot of the RPV used in this role does not actively control the vehicle and its weapons release, he will surely be expected to observe and check on the RPV's performance and to assess results of the strike.

For monitoring, a vidicon, a FLIR, or a radar could be used. Control of sensor pointing by the "pilot" is mandatory. The sensor (or optics for it) must be located beneath the RPV and forward to provide a clear view of the ground ahead and below. Outputs from the sensor will be transmitted to the operator aboard the launch/recovery vehicle. The same data will be processed by the tracking system for solution of the stores release problem. Commands from the pilot are received by a receiver aboard the RPV to maneuver either the visual sensors and/or the vehicle. Once target tracking has started, the RPV will be under control of the weapon release computer unless overridden by the pilot.

Requirements for monitoring the performance of an RPV in an air-to-air role will be more stringent than those for an air-to-ground system. Not only may it be necessary to search for and acquire an airborne target, but the remotely located pilot may have to become the gunner if the vehicle is to have cannons. In this case the display may contain the imagery in the cannon firing effectiveness zone ahead of the vehicle together with the symbology of a gunsight. The sensor aboard the vehicle "sees" the same scene a pilot would see if he were located in the RPV and looking through his gunsight HUD. The sensor(s) used must have wider ranges of gimbal angles and much higher angular acceleration and velocity capabilities in order to follow maneuvering aircraft at short range.

The RPV could carry air-to-air missiles in its dogfight role. Here the problem would be similar to the air-to-ground weapon delivery problem. The monitoring requirements would involve searching for the target, acquiring it, and initiating lock-on. From then on the monitor would check to assure that the RPV has maneuvered to within an acceptable launch region near the target. The remote pilot could then initiate missile launch and use his monitor sensors to determine the success of his attack.

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